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HOW IT WORKS

AMAZING CHEMISTRY

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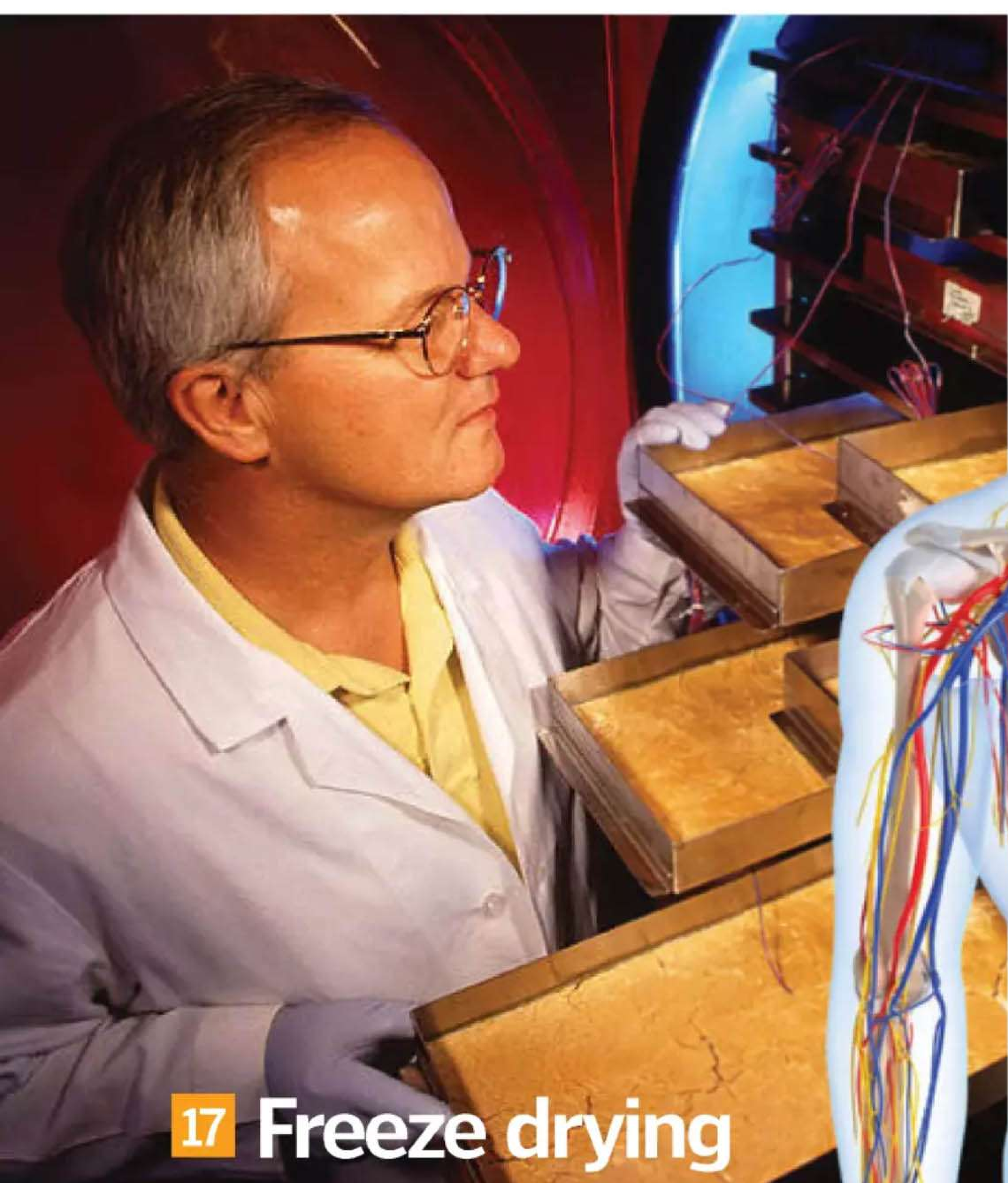

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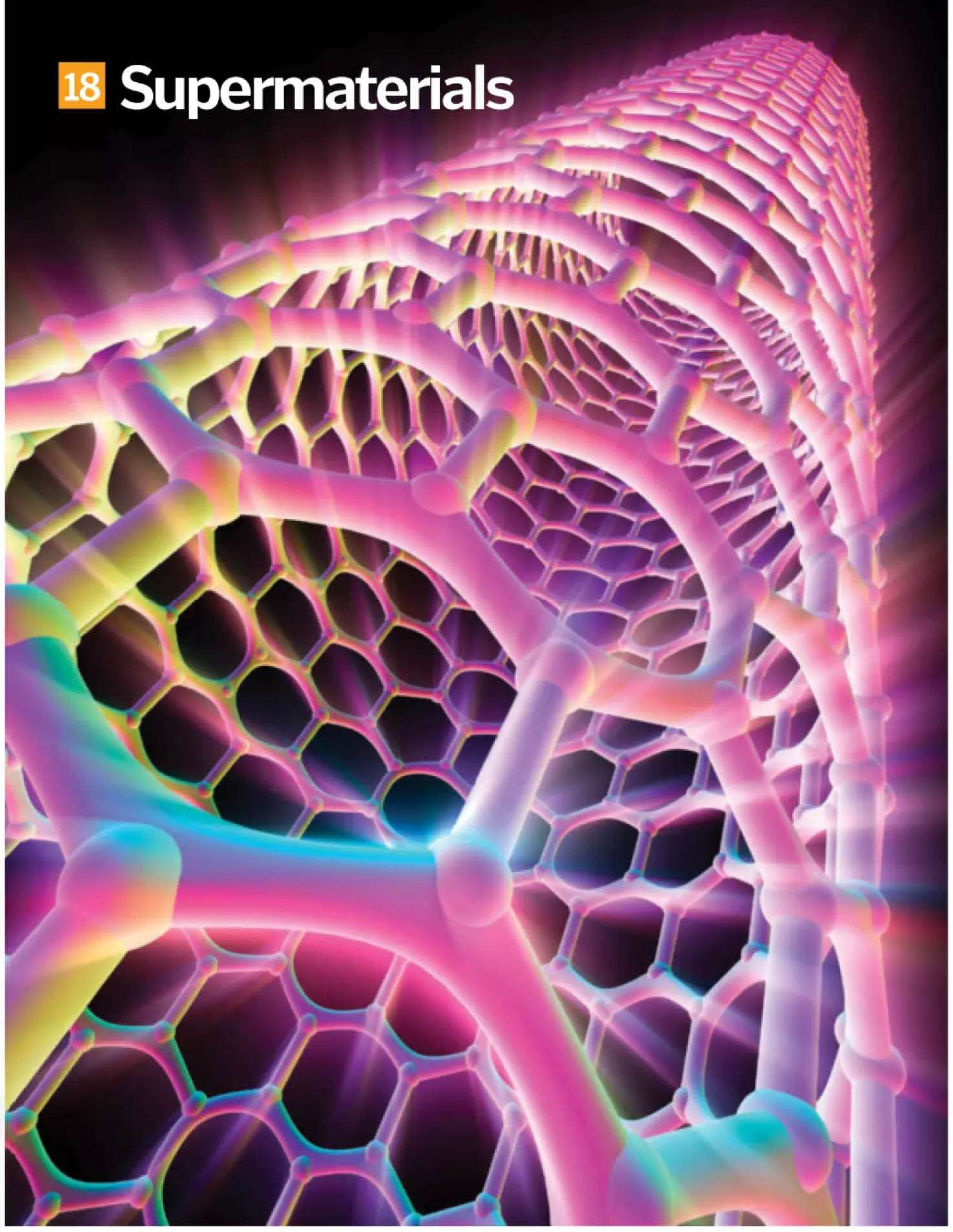
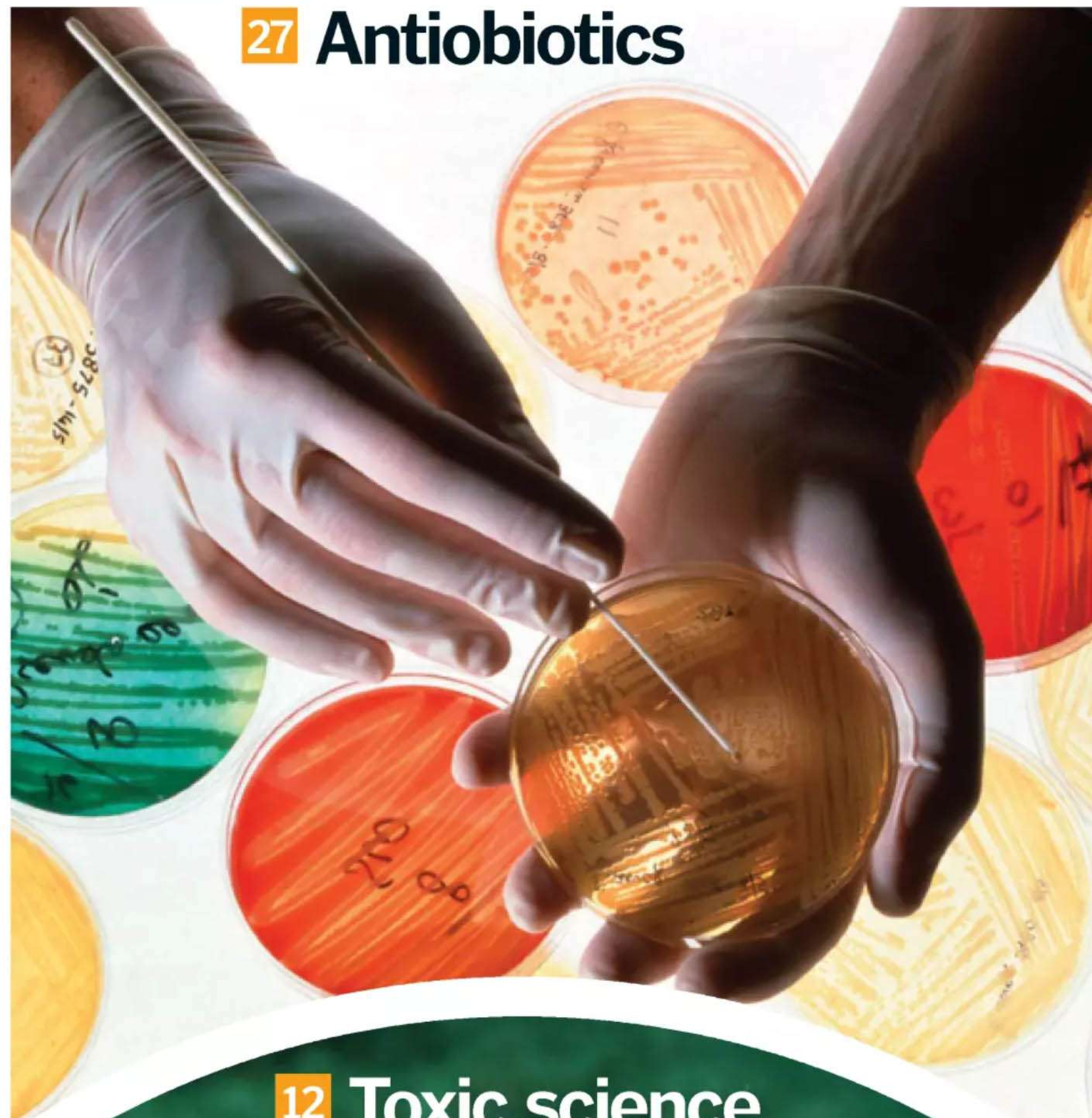




AMAZING CHEMISTRY

Ten of Earth's most awe-inspiring chemical and physical reactions at an atomic level

Chemistry is a fascinating subject. The way atoms behave determines everything from the food we eat and the clothes we wear, to our genetic makeup and how we feel. The beautiful simplicity of the periodic table describes just 118 elements that form every known material – 98 if you discount those that can only exist in a laboratory. These elements react in a variety of ways, forming hundreds of millions of compounds – two or more elements bonded together – giving us the diversity of materials that make up our world.

Some reactions are physical, not chemical, and the way to tell is whether or not there has been a change in the chemical formula. Melting ice is a physical change because water is the same substance as ice, just in a different state of matter. Burning coal, on the other hand, is a chemical change, as coal and oxygen combine to make carbon monoxide – a chemically unique material. A chemical reaction drives the change of one substance into another and the reactions are generally identified by colour changes or a release of energy – often in the form of heat, light and sound: the ingredients of an explosion.

It is impossible to cover the astonishing range of chemical reactions that happen in our universe in one article, so we've picked ten standout ones which have dramatic results.

1. CORROSIVE

Iron oxide (rust)
Given enough time, iron either left in water, or in contact with water vapour in air, will rust – forming iron oxide.

2. VERY CORROSIVE

Battery acid
Due to the corrosive nature of sulphuric acid – commonly found in car batteries – the terminals on the battery tend to corrode after a few years.

3. MOST CORROSIVE

Hydrofluoric acid
Hydrofluoric acid is a relatively weak acid, yet it corrodes most metals and can even dissolve glass, so it's used in glass etching.

DID YOU KNOW? *A catalyst is a substance added to speed up chemical reactions, while inhibitors slow them down*

Reaction types

Distinguishing between physical and chemical reactions is one thing, yet chemists have identified five common ways that chemical changes can be broken down further. These are: synthesis, decomposition, single replacement, double replacement and oxidation/reduction (redox).

Some reactions can exhibit characteristics of more than one of these labels – as all chemical reactions are caused by the sharing, gaining or losing of electrons. However it's helpful to categorise reactions by the distinct ways in which they behave.

Synthesis

A synthesis reaction occurs when two or more chemical elements or compounds react together to make a more complicated compound. For example – burning hydrogen (H_2) and oxygen (O_2) gas forms the more complex water molecule (H_2O).

$A + B \rightarrow A\text{-}B$

Decomposition

Decomposition is the breaking down of two or more complex molecules into simpler ones. Passing an electric current through water (H_2O), results in the 'decomposition' of the water molecule into its basic elements: hydrogen (H_2) gas and oxygen (O_2) gas.

$A\text{-}B \rightarrow A + B$

Single replacement

When one element is bumped by another in a compound, it's a single replacement reaction. Reactions with metals and acids often fall into this group. Magnesium (Mg) and hydrochloric acid (HCl) react to form magnesium chloride ($MgCl_2$) and hydrogen (H_2), where Mg replaces H_2.

$A\text{-}B + C \rightarrow A\text{-}C + B$

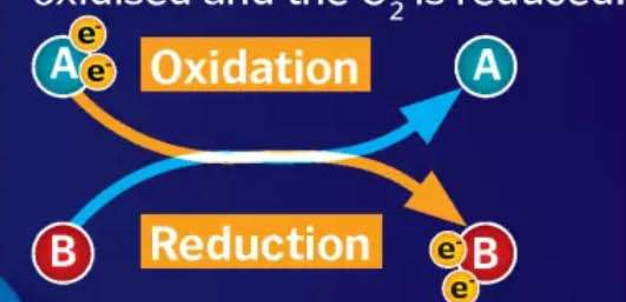
Double replacement

In some cases, compounds 'swap' their components – this is called a double replacement reaction. For example, hydrochloric acid (HCl) and sodium hydroxide (NaOH) react together, producing sodium chloride (NaCl) and water (H_2O). In this reaction, the hydrogen and sodium atoms have switched places.

$A\text{-}B + C\text{-}D \rightarrow A\text{-}C + B\text{-}D$

Redox

Oxidation and reduction (ie redox reactions) describe a chemical change where electrons are transferred. You can't have oxidation (loss of electrons) without reduction (gain of electrons). When H_2 burns with O_2, the H_2 becomes oxidised and the O_2 is reduced.



THE METAL MELTER

Thermite reaction

Deadliness: ☠☠☠☠
Ingredients: Aluminium (Al); iron oxide (Fe_2O_3)
Core process: Single replacement

✗ In nature ✓ In lab ✗ At home ✗ Toxic

Thermite is a very cool – well, hot – reaction that consists of metal powder and a metal oxide (most often aluminium and iron oxide); the latter more commonly known as rust. The characteristics of thermite reactions are not so much explosive; rather it's their ability to heat very small areas to incredibly high temperatures where they excel. You don't think of metals as burning very easily, but in the right conditions – and very high ignition temperatures – they can.

Thermite reactions are used for welding train tracks together and temperatures as high as 2,500 degrees Celsius (4,532 degrees Fahrenheit) can be reached. Due to the blazing heat, products of thermite reactions are liquid, making them perfect for welding. As thermite reactions have their own supply of oxygen from the metal oxide they can work even in the absence of air, such as underwater and in space.

Aluminium and iron oxide are heated, often with magnesium ribbon as a fuse, and oxygen from the iron oxide breaks its bond to combine with the aluminium to form aluminium oxide and iron. Special face masks with UV protection must be worn when welding due to the intense radiation.

THE CRYSTALLISER

Copper sulphate crystals

Deadliness: ☠
Ingredients: Copper sulphate pentahydrate ($CuSO_4$*$5H_2O$); water (H_2O)
Core process: Crystallisation

✓ In nature ✓ In lab ✓ At home* ✓ Toxic

*(But take care as copper sulphate can be a mild irritant)

What it lacks in explosive power, copper sulphate more than makes up for in its looks – creating brilliant blue crystals when its hydrated form is dissolved in hot water. Copper sulphate is a type of salt, and is most commonly encountered as a powder – copper sulphate pentahydrate ($CuSO_4$*$5H_2O$). This is a way of expressing five water molecules are attached to the copper sulphate molecule; it is hydrated. For blue crystals to form, copper sulphate pentahydrate is added to hot water up until the point where no more can dissolve. This is referred to as a saturated solution, and a hotter solution can dissolve more copper sulphate than a colder one. When the solution starts to cool, some of the copper sulphate can no longer exist in a dissolved state, so the molecules gather in an organised repeating pattern, forming crystals. This is an example of a physical change since the material is altering its structure rather than its makeup. Suspending a nylon wire in the solution creates a surface for the crystals to latch on to, encouraging growth. Eventually the water evaporates, but copper sulphate can't so it's forced into an ever-smaller space. The molecules of copper sulphate continue crystallising until no water is left.

“The light from a pure hydrogen and oxygen reaction is mainly ultraviolet, making the flame almost invisible”

Top five deadliest reactions

1 Hydrochloric acid and most things…
Hydrochloric acid (HCl) is an extremely strong acid. HCl reacts with most things – especially bases – and can corrode metal, cause chemical burns and even release flammable hydrogen.

2 Acid rain
When sulphur dioxide is released into the air, it rises up and reacts with hydrogen peroxide which is found in some clouds. Sulphuric acid – a product of the reaction – falls back down to Earth and can have devastating effects on flora, fauna and buildings/statues, etc.

3 Nitroglycerine and heat
Nitroglycerin is one of the most explosive substances there is. The oily liquid is so sensitive that the slightest jolt or increase in heat can trigger a massive explosion.

4 Bleach and ammonia

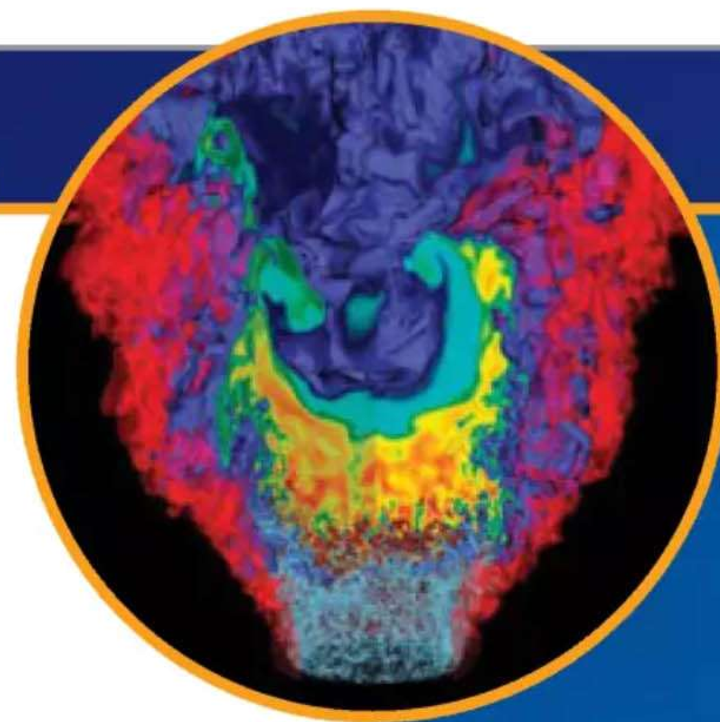
When ammonia and bleach are mixed, the bleach decomposes to form hydrochloric acid. Ammonia and chlorine gas react to form a deadly vapour: chloramine.

5 Mustard gas
The volatile combination of sulphur dichloride and ethylene reacts to form a cyclic sulphonium ion. This reacts with parts of DNA to prevent cells from replicating, leading to tissue necrosis.

THE FIRESTARTER

Burning hydrogen

Deadliness: ☠☠☠
Ingredients: Hydrogen (H_2); oxygen (O_2)
Core process: Redox
✖ In nature ✓ In lab ✖ At home ✖ Toxic



Hydrogen (H_2) is the lightest, most abundant element in the universe, yet it's also one of the most flammable. Hydrogen is quick to burn in the presence of oxygen (O_2) and can be very explosive. Used as the primary fuel for combustion when launching space shuttles, this is seriously powerful stuff. When hydrogen burns, large quantities of heat and light are given off. The light emitted from a pure hydrogen and oxygen reaction is mainly ultraviolet, making the flame almost invisible – however, in reality, there are often other materials present, creating a visible flame. Water is the waste product of hydrogen combustion, since oxygen and hydrogen are the two ingredients in water. Combustion of liquid hydrogen and oxygen is used to launch rockets – hence it is water vapour, not smoke, which you see coming out of the exhaust during the takeoff.

Scientists are now working on using hydrogen combustion to power cars and other machines. The difficulty is the large amount of initial energy needed to get the reaction going. It requires far more energy to get started than, say, traditional fossil fuels.

Hydrogen is rarely found on Earth in its pure form, because it prefers to join with other elements – and of course a great deal exists as water.

THE BOMB DECOY

Magnesium and Teflon

Deadliness: ☠☠☠
Ingredients: Magnesium (Mg); Teflon ($[C_2F_4]n$)
Core process: Redox
✖ In nature ✓ In lab ✖ At home ✖ Toxic

Magnesium (Mg) is a highly reactive element which burns at a staggering 3,100 degrees Celsius (5,612 degrees Fahrenheit), giving off an intense white light. In addition to visible light, magnesium emits infrared (IR) when burned, making it perfect for use in military countermeasures such as decoy flares. Like all things, magnesium needs to be in the presence of an oxidiser when it burns – a material which takes electrons from the fuel allowing the reaction to occur. Flares are made of Teflon ($[C_2F_4]n$) and magnesium, and it's the fluorine in Teflon that oxidises magnesium. Fluorine is a stronger oxidiser than oxygen, as it wants to accept electrons more than oxygen, allowing for a higher temperature of combustion. Heat-seeking missiles lock on to infrared light given off by engines in aircraft, but magnesium decoy flares throw out far more IR light than aeroplane engines, effectively confusing the missiles' heat-seeking guidance systems and hopefully deterring the weapon from its target.

A magnesium fire cannot be extinguished with water, since the magnesium reacts with water to produce hydrogen gas – which if anything will only intensify the fire. Instead, dry sand is generally used to stop the reaction. Other uses of magnesium have been as an illumination source in flash photography and in fireworks.

THE SOLIDIFIER

Sodium acetate supersaturation

Deadliness: ☠ **Ingredients:** Sodium acetate ($NaC_2H_3O_2$); water (H_2O)
Core process: Crystallisation

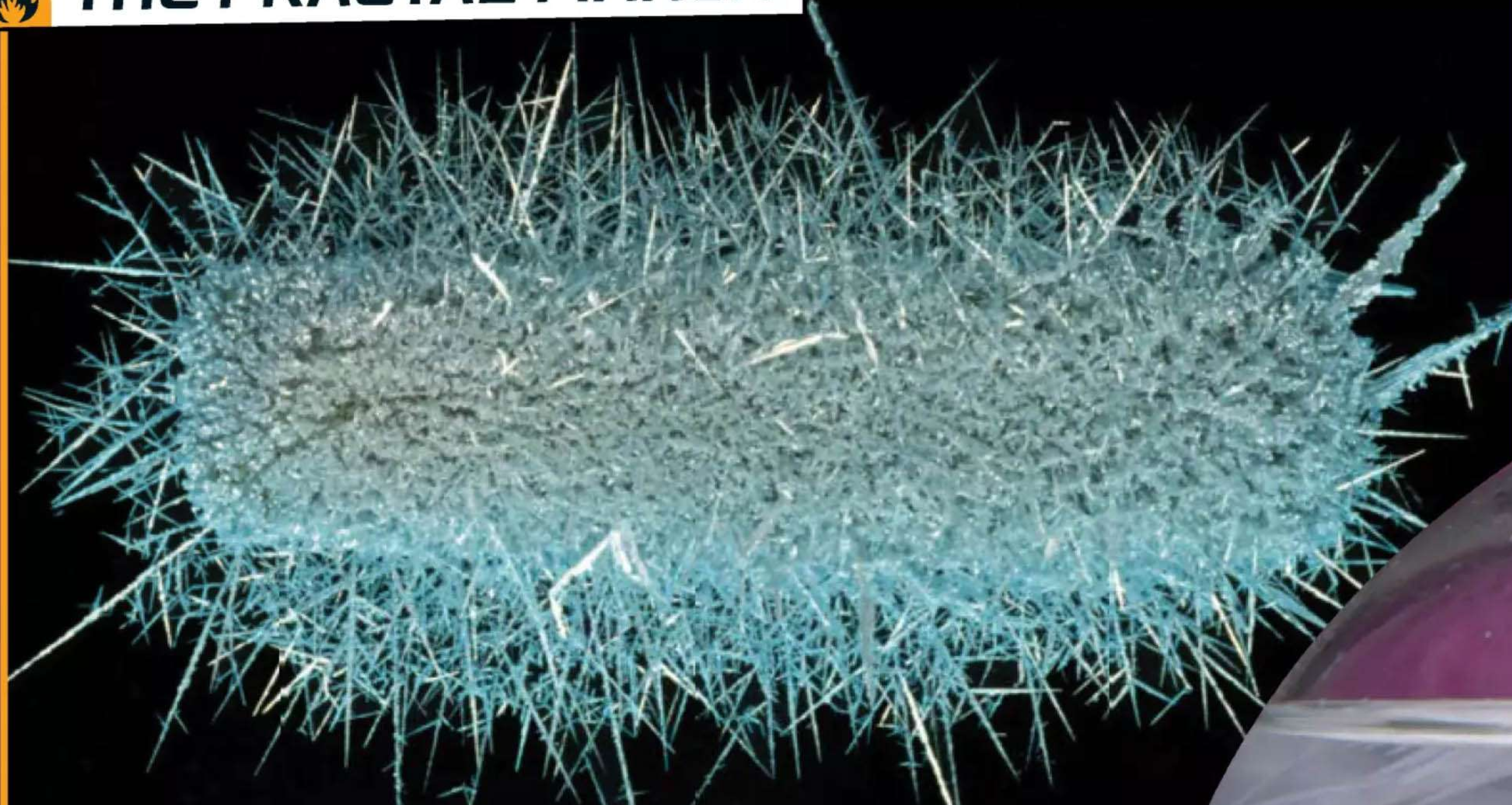
✖ In nature ✖ In lab ✓ At home* ✖ Toxic *(Heat is given off but not enough to cause burns)

Sodium acetate ($NaC_2H_3O_2$) heated in water then cooled has the unusual property of crystallising into a solid when it is disturbed. It can be poured out of a beaker as a liquid and, upon hitting a surface, becomes a solid that is hot to touch – hence its other name, hot ice. Sodium acetate is a salt which dissolves in water. Heating – to around 100 degrees Celsius (212 degrees Fahrenheit) – then cooling a mixture of the two allows more sodium acetate to dissolve to form a supersaturated solution. The solution exists in a metastable state, analogous to a ball perched at the top of a hill, where the slightest nudge will make it roll down.

The trigger can be pouring the solution out of the container, or adding a seed crystal, causing the dissolved sodium acetate to come out of the solution and return to a solid. In our analogy this is like the ball rolling down the hill until it reaches flat ground and a lower energy state.

Along the way, the solid sodium acetate absorbs three molecules of water, becoming sodium acetate trihydrate ($NaC_2H_3O_2*3H_2O$). These water molecules are not chemically bonded to the sodium acetate, representing a physical change. The process is exothermic (ie it releases heat) and, as a result, it's often used in hand warmers.

THE FRACTAL MAKER



Copper and silver nitrate

Deadliness: ☠
Ingredients: Silver nitrate ($AgNO_3$); copper (Cu); water (H_2O)
Core process: Single replacement

✖ In nature ✓ In lab ✖ At home ✓ Toxic

Mixing silver nitrate and copper is one of the most famous chemistry experiments, with it starring in many a school science lesson around the globe. The experiment involves introducing copper – typically a copper wire – to a silver nitrate/water solution and suspending it there for a couple of hours.

The combining of both triggers a single replacement reaction, where copper is changed from its elemental form (Cu) to its blue aqueous ion form (Cu_2+ [aq]), while the silver ions (Ag+ [aq]) in the silver nitrate solution will be changed into their elemental metallic form (Ag) and deposited onto the wire. These silver deposits continue to grow off the copper in a series of fractal-like crystals until all reactable copper in the solution is exhausted, leaving the end products of silver and copper nitrate.

The reason this replacement reaction occurs is that the atoms in the copper are oxidised when introduced to the silver nitrate solution, losing electrons and forming copper ions, while the silver ions in the nitrate solution are reduced (ie they gain electrons) into elemental silver.

What's really cool is that once the silver crystals have grown they can be removed from the copper, dried off and then displayed as funky pieces of fractal art.

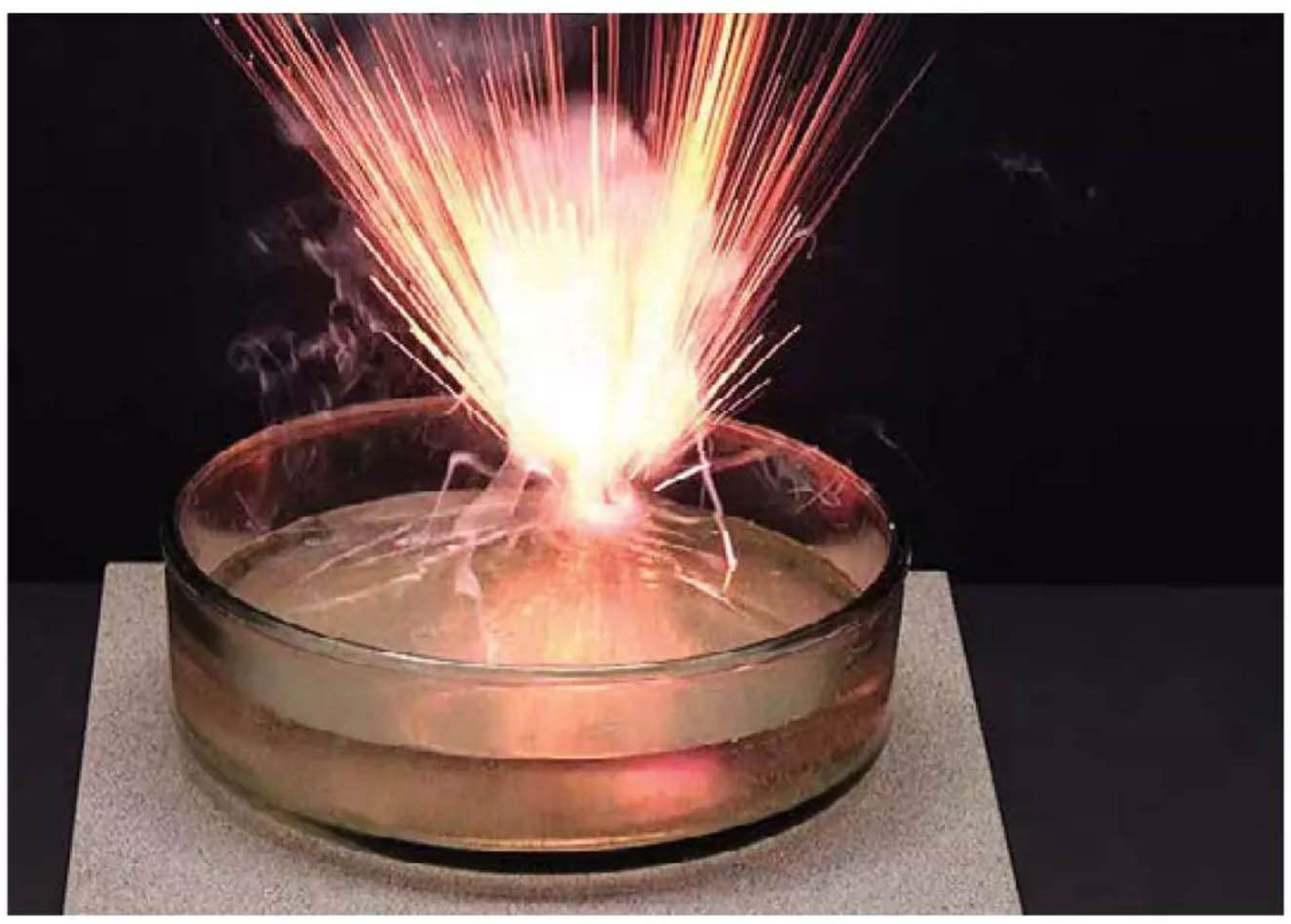
THE WITCH'S POTION

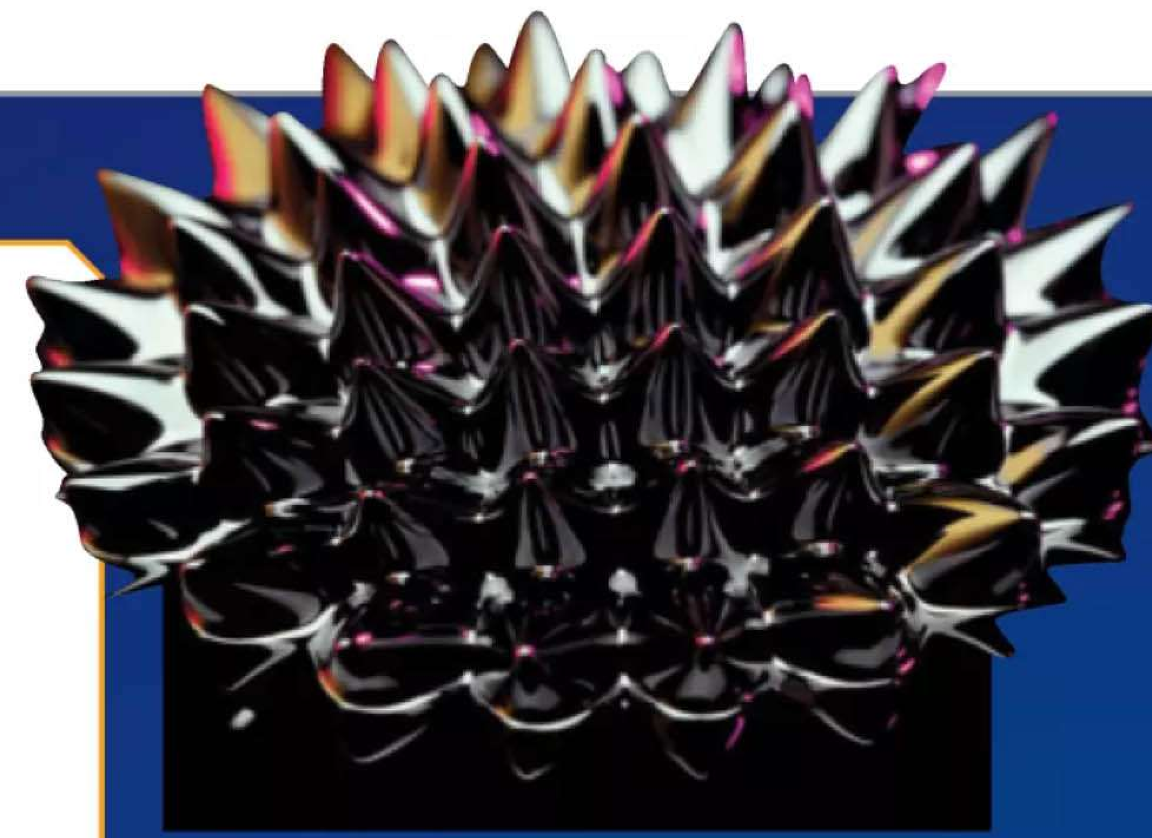
Potassium and water

Deadliness: ☠☠☠
Ingredients: Potassium (K); water (H_2O)
Core process: Redox

✖ In nature ✔ In lab ✖ At home ✖ Toxic

Put a lump of potassium in a dish of water and it will give off a pinkish light, get very hot and skim across the surface at speed. A favourite experiment of many science classrooms, potassium is a highly reactive metal that reacts violently in the presence of oxygen and water. It forms potassium hydroxide (KOH) and hydrogen gas (H_2). Potassium atoms have 19 electrons – one of which is alone in an outer shell. This makes potassium very keen to lose an electron so it has a complete outer shell and is more stable. When the reaction begins, enough heat is given off to ignite the hydrogen gas, which then reacts with oxygen to produce water. Potassium is so reactive that it must be stored in kerosene, so as not to come into contact with water vapour in the air. Even oxygen in the air is enough to cause potassium to spontaneously combust! Because potassium is so reactive, it's not found in its elemental form, but is common as a compound.





Ferrofluid

This experiment combines physics and chemistry to produce an awesome effect. Ferromagnetic fluid is a liquid that undergoes a radical change when introduced to a magnetic field, turning from a puddle into a spiked dome. The fluid does this due to its composition, which is a mix of nanoscale ferromagnetic particles (like iron) and a carrier fluid. The particles are coated with a surfactant – a compound that lowers a liquid's surface tension – ensuring an even distribution of particles. When a magnetic field is introduced – usually a strong magnet positioned beneath it – the particles realign to the magnetic field lines. Contained as they are, the particles cause the liquid to act like a solid.

THE SCREAMING JELLY BABY

Potassium chlorate and most things (in this case Jelly Babies)

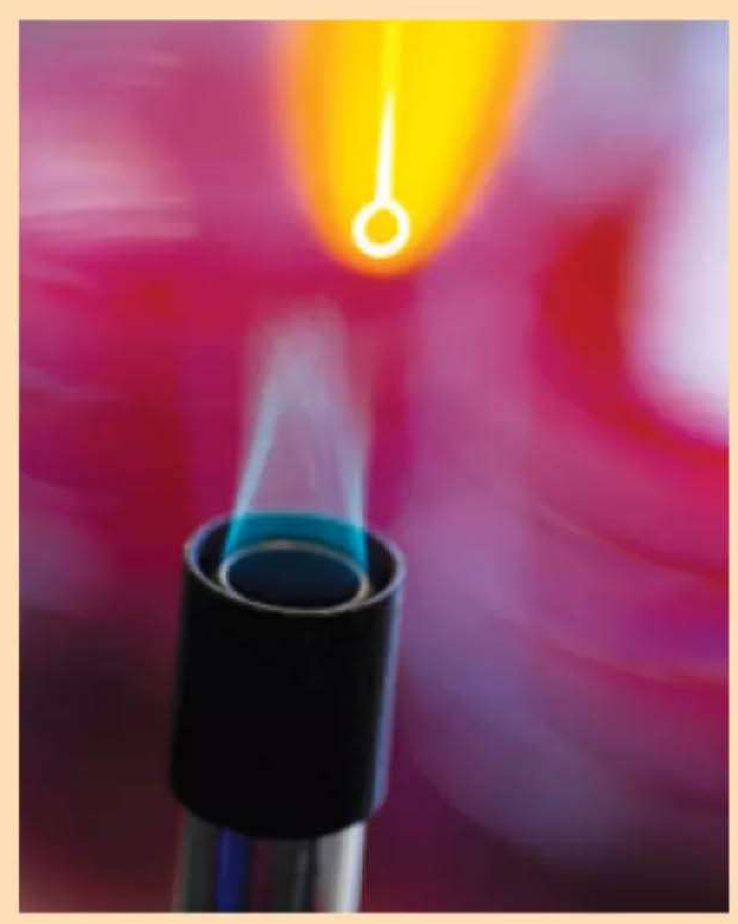
Deadliness: ☠☠☠
Ingredients: Potassium chlorate ($KClO_3$); Jelly Babies (glucose syrup, sugar, water, gelatine and flavourings)
Core process: Redox

✖ In nature ✔ In lab ✖ At home ✔ Toxic

Watching a Jelly Baby meet its demise at the hands of potassium chlorate is a spectacular affair. There's an abundance of energy inside Jelly Babies stored as sugar, released in intense flames and a piercing scream when potassium chlorate is added to the mix.

Potassium chlorate is a powerful oxidiser, taking its form as a white powder and commonly used in fireworks and explosives. The 'ate' part of chlorate describes the oxygen atoms attached to the chlorine atom, and the chemical formula is $KClO_3$. Chlorate-based oxides are more efficient oxidisers than those in gunpowder and potassium chlorate needs to be handled very carefully due to its unpredictable ability to spontaneously ignite.

The reaction happens when a small amount of potassium chlorate is placed in a test tube and heated until it becomes a clear liquid. Needless to say, safety screens and goggles are a must. The Jelly Baby is placed with tongs into the tube and instantly produces lively flames, intense screaming and plenty of smoke. The reaction can last up to 20 seconds and gives off noxious fumes so ventilation is also needed.



Flame test

The flame test is one of the simplest yet coolest experiments in the lab. By introducing certain elements – generally metals – to a Bunsen burner, you can determine their composition by analysing the emission spectrum. This works as the heat excites the material's ions, so they emit visible light. For example, if you have a chunk of unknown metal, by introducing it to a calibrated burner (one that is not contaminated) and evaluating the colour(s) of the flame, you can determine what the substance is made of. Copper (Cu) emits a blue-green flame, lithium (Li) a bright red one, while the image above shows the orange/crimson flame generated by strontium (Sr).

Which is the strongest acid?

A Citric acid B Stomach acid C Bleach

Answer:
Stomach acid is stronger than citric acid and bleach – the latter isn't even an acid. Stomach acid measures between 1.5 and 3.5 on the pH scale and contains potent hydrochloric acid. It serves to kill any harmful microbes and bacteria we consume.

DID YOU KNOW? Superacids are acids with an acidity greater than that of 100 per cent sulphuric acid

THE BARKING DOG

Carbon disulphide and nitrous oxide

Deadliness: ☠☠☠
Ingredients: Carbon disulphide (CS_2); nitrous oxide (N_2O)
Core processes: Decomposition; redox

✓ In nature (the reactants) ✓ In lab ✗ At home ✓ Toxic

The barking dog reaction is a consequence of igniting carbon disulphide (CS_2) mixed with nitrous oxide (N_2O) – the latter is better known as laughing gas. The reaction generates a bright flash of blueish-purple light and heat, and, more bizarrely, a sound like a dog barking.

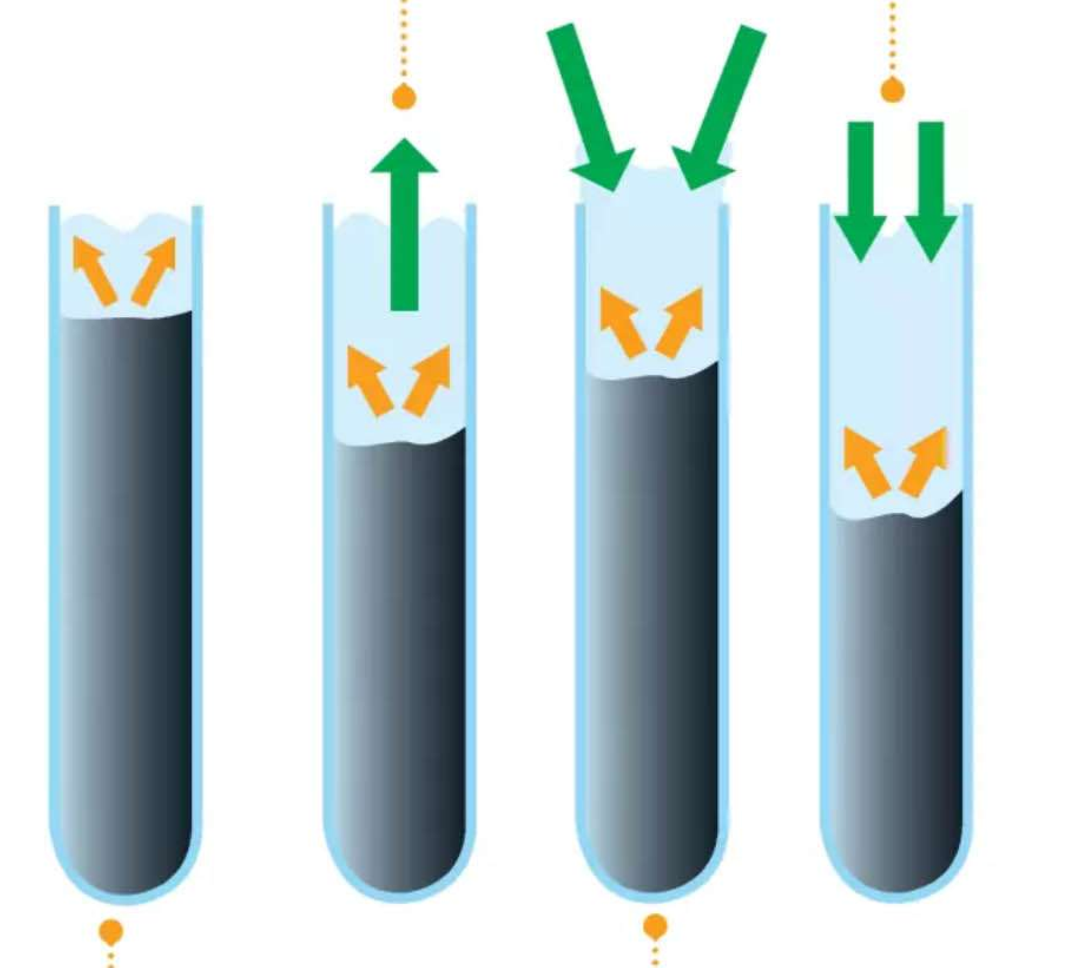
Nitrous oxide gas is the source of oxygen – ie the oxidiser – needed to burn the colourless liquid fuel, carbon disulphide. When the reaction takes place in a confined space – such as a long tube – some energy is converted to form the rapid but loud barking noise, due to a fluctuation of pressure. This is an example of a reaction which makes elements from compounds: in this case a yellow coating of sulphur and nitrogen gas are the elements left in its wake.

Carbon disulphide is found in nature as a product of the metabolic processes in plants, and also volcanic eruptions. Nitrous oxide also forms naturally from some species of bacteria, plus through industry and agriculture, and it depletes ozone in the stratosphere.

Used in the distant past as a method of flash photography, the flash it produces is so bright that many people in the photographs would often appear startled. The pervasive smell that sulphur compounds are capable of probably didn't make it that popular either.

2. Expansion
As the gases expand, those near the top are forced out of the test tube due to pressure.

4. Bark
As the gases rush back into the tube to balance the pressure, a repeated 'barking' noise is made.



1. Energy release
Nitrous oxide reacts with the carbon disulphide releasing energy as heat, expanding the gases.

3. Differential
The expelled gases lead to a pressure drop within the tube, creating a vacuum-like effect.

THE CANDY ROCKET

Potassium nitrate and sugar

Deadliness: ☠☠
Ingredients: Potassium nitrate (KNO_3); sucrose ($C_{12}H_{22}O_{11}$)
Core process: Redox

✗ In nature ✓ In lab ✗ At home ✓ Toxic

There's something strangely satisfying about witnessing the volatile display of smoke, colour and fire given off by the mixture of potassium nitrate, sugar and heat. The amount of fire varies, but there is always an abundance of smoke. You have most likely seen this reaction at a firework display, or from the smoke stunt planes deploy where coloured dyes are often added for effect.

Potassium nitrate (KNO_3)– aka saltpetre – is an essential in any pyrotechnics cookbook; it's one of the main ingredients in gunpowder, for example. Potassium nitrate works as an oxidiser, giving off oxygen and promoting the burning of fuel.

As seen in the 'Screaming Jelly Baby', sugar is an extremely effective fuel; it contains energy that 'burns' in our bodies and converts to useful energy we use to perform any physical activity. When heat is applied to saltpetre and sugar, the saltpetre loses an oxygen atom – transitioning from KNO_3 to KNO_2 and oxidising the sugar. The sugar burns, releasing smoke which rapidly expands and can generate enough thrust to lift a small rocket.

Interestingly there's a programme called Sugar Shot to Space that aims – as you would probably guess – to launch a rocket powered by sugar propellant alone beyond Earth's atmosphere.

Useful reactions

1 Photosynthesis
The chemical process of turning sunlight into energy is vital to life, allowing plants to grow and release their waste product: oxygen. As well as regulating the levels of oxygen in the atmosphere, photosynthesis is the source of energy for most organisms.

2 Baking bread
In times when other food sources were scarce, the discovery of heating flour mixed with water combined with yeast fermentation was a breakthrough. Yeast ferments sugars and carbohydrates giving off CO_2.

3 Extraction of metals
One of the world's largest industries, extracting metals from their ores using chemical reactions is hugely important, as most metals are mixed with impurities in their natural state.

4 Galvanising steel
From lampposts to buildings steel is everywhere around us and protecting these things from rust is vital. Dipping steel in a bath of zinc causes a chemical reaction which adheres a coating of zinc to the steel to protect it from water vapour.

5 DNA production
The essential 'code' for all known life, DNA is a molecule with our genetic instructions in the form of nucleotides – a set of long polymers made of sugars and phosphates. Chemical reactions allow the DNA to form, replicate and interact with proteins to make us who we are.

> "By bombarding atomic nuclei with protons or smaller nuclei, scientists have synthesised 20 more elements"

The periodic table

Unlock the wealth of information inside this handy guide to all the elements

The periodic table makes scientists' jobs easier by providing a visual guide to each element's main properties.

An element is a substance made from just one type of atom – carbon, for example. The Big Bang produced a handful of very light elements – mostly hydrogen and helium – which were fused inside stars into many heavier elements, like iron. Add to these another 14 elements produced by radioactive decay and you have our universe's 98 naturally occurring elements.

But it doesn't end there. By bombarding atomic nuclei with protons or smaller nuclei, scientists have synthesised 20 more elements. Produced inside nuclear reactors or particle colliders, these are the heaviest elements in the table, with atomic numbers 99 to 118. Since they are all radioactive, they decay rapidly – some after a few days or weeks, but many in a few fleeting milliseconds. This leaves scientists very little time to assess the properties of new discoveries. While they await official recognition, these elements are assigned temporary names such as Ununoctium.

The periodic table organises all 118 elements in order of increasing atomic number. This long list is then split into rows (called periods) according to how many electron shells each element has. Many of an element's chemical properties are determined by the configuration of electrons sitting in their shells. Elements with just one electron in their outer (valence) shell, for instance, react very easily. Elements in the same column (called a group), meanwhile, have similar electron configurations and therefore share characteristics like reactivity.

A number of other patterns can be found across the entire table. Metallic properties, for example, gradually disappear as you move from the bottom-left corner to the top-right.

Non-metals
With a dull finish, non-metals don't conduct heat or electricity well.

Transition metals
These are hard, with high melting and boiling points.

Poor metals
These malleable metals have fairly low melting and boiling points.

Alkali metals
With just one electron each, alkali metals are very reactive elements.

Metalloids
Despite looking metallic, metalloids are brittle and most act like non-metals.

Alkaline earth metals
Keen to give up two electrons, these metals bond easily.

Halogens
Halogens are just one electron shy of full shells, making them very reactive.

Lanthanoids
These soft metallic elements, known as rare earth metals, are very reactive.

Noble gases
With full outer shells, noble gases rarely react with other elements.

Actinoids
Actinoid radioactive elements exist naturally, while others are manmade.

Period / Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.01																	2 He Helium 4.01
2	3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 15.99	9 F Fluorine 18.99	10 Ne Neon 20.18
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminium 26.98	14 Si Silicon 28.08	15 P Phosphorus 30.97	16 S Sulfur 32.65	17 Cl Chlorine 35.45	18 Ar Argon 39.95
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.97	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.91	36 Kr Krypton 83.79
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niob 92.91	42 Mo Molybdenum 95.96	43 Tc Technetium (97.91)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.91	54 Xe Xenon 131.29
6	55 Cs Caesium 132.91	56 Ba Barium 137.33	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (208.98)	85 At Astatine (209.98)	86 Rn Radon (222.02)
7	87 Fr Francium (223)	88 Ra Radium (226)	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadium (271)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)	113 Uut Ununtrium (284)	114 Fl Flerovium (289)	115 Uup Ununpentium (288)	116 Lv Livermorium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)
Lanthanoids			57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 157.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97	
Actinoids			89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.02	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)	

What's the most abundant element in your body?

A Hydrogen **B** Carbon **C** Gold

Answer:
Our bodies are mostly water (H_2O), so as a result hydrogen makes up 67 per cent of the average human body's total 7 x 10^{27} atoms. Because hydrogen is very light, however, it only accounts for around ten per cent of our mass.

DID YOU KNOW? *The element mercury owes its unusual chemical symbol – Hg – to hydrargyrum, Latin for 'liquid silver'*

Building blocks

Take a glance at the key information displayed in each element on the table

Atomic number
The number of protons and electrons in the element.

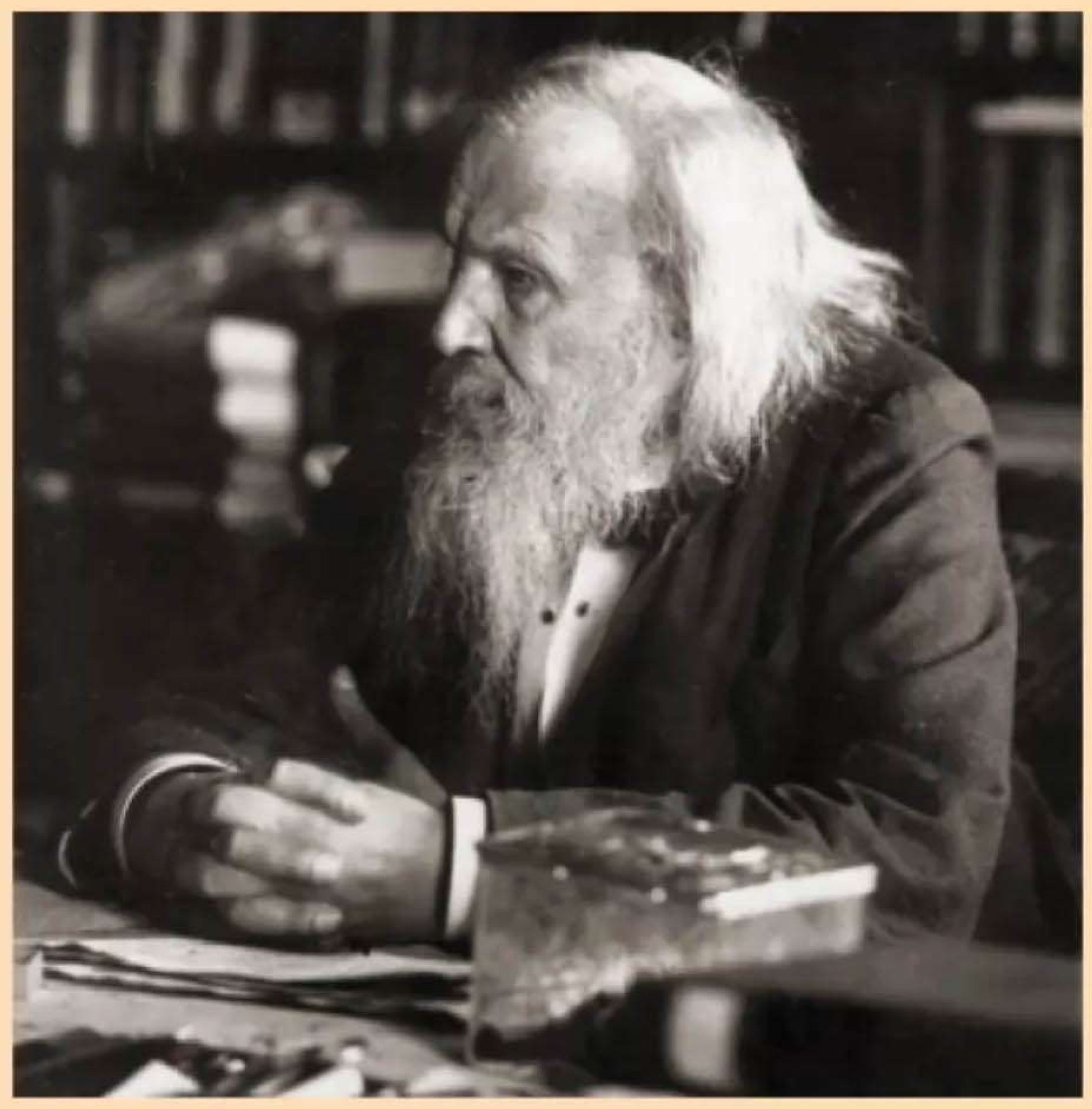
Chemical symbol
One or two letters used as a short form to represent the element.

12
Mg
Magnesium
24.31

Title
The element's full name for those who don't know their symbols.

Atomic mass
The mass of an atom, which is measured in atomic mass units. This also takes into account the atom's neutrons.

Mendeleev's table



Russian chemist Dmitri Mendeleev published one of the earliest versions of the periodic table in 1869, laying the foundations for the table we know today. Ordering over 60 known elements according to their atomic weight, he noticed that elements with similar properties occurred at regular intervals – in other words, periodically. Grouping elements to reflect these trends, three gaps remained. Mendeleev concluded that undiscovered elements must fill these gaps, deducing some of their properties from their position in the table. The discovery of gallium, scandium and germanium soon after confirmed Mendeleev's predictions, and scientists worldwide adopted his table. Over the years, Mendeleev's table has been updated to include previously unknown groups of elements such as the noble gases, and re-ordered by atomic number to create a more accurate arrangement.

Grouping the elements

The table's 18 groups, displayed in columns, have the most in common due to their shared electron configurations. Trends also exist within groups. For example, as you move from top to bottom, you need more energy to tear an electron away from its atom (ie ionisation energy increases).

Within periods, the table's horizontal rows, similar patterns exist but they are generally weaker. Periods owe their shared characteristics to having the same number of electron shells. Generally, as you move from left to right, elements become more reactive and their size (atomic radius) increases.

Period 3

11 Na Sodium 22,99	12 Mg Magnesium 24,31	13 Al Aluminium 26,98	14 Si Silicon 28,08	15 P Phosphorus 30,97	16 S Sulfur 32,65	17 Cl Chlorine 35,45	18 Ar Argon 39,95

Sodium
Outer shell electrons: **1**
Protons in nucleus: **11**
How reactive relative to other elements:
Extremely reactive

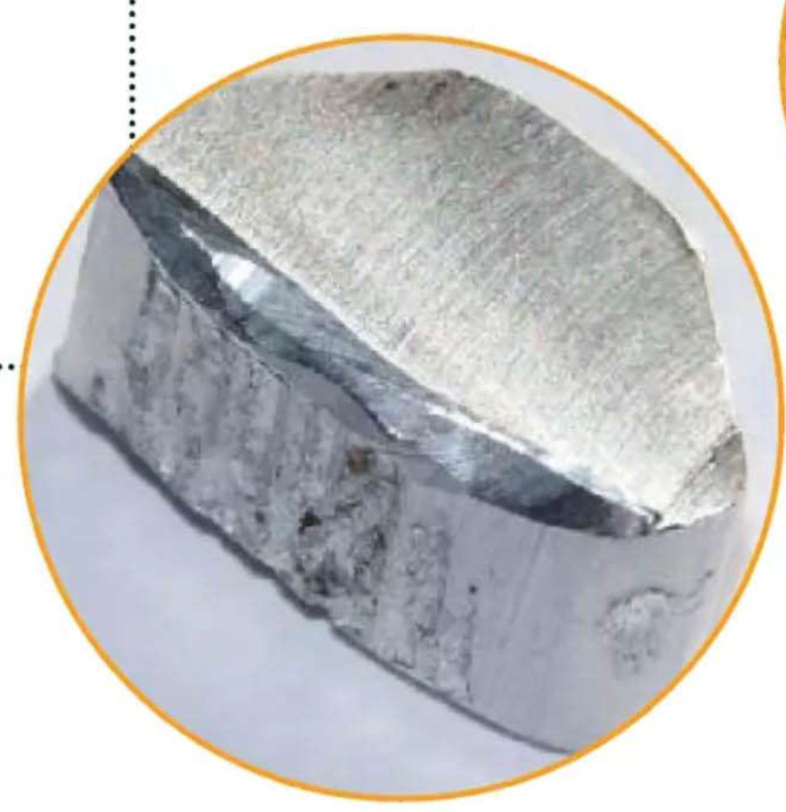
Silicon
Outer shell electrons: **4**
Protons in nucleus: **14**
How reactive relative to other elements:
Relatively unreactive

Phosphorus
Outer shell electrons: **5**
Protons in nucleus: **15**
How reactive relative to other elements:
Reactive

Chlorine
Outer shell electrons: **7**
Protons in nucleus: **17**
How reactive relative to other elements:
Highly reactive

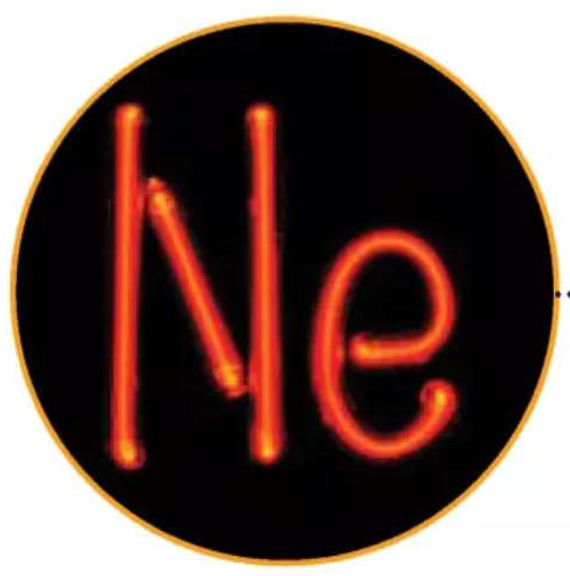
Magnesium
Outer shell electrons: **2**
Protons in nucleus: **12**
How reactive relative to other elements:
Highly reactive

Sulphur
Outer shell electrons: **6**
Protons in nucleus: **16**
How reactive relative to other elements:
Reactive



Aluminium
Outer shell electrons: **3**
Protons in nucleus: **13**
How reactive relative to other elements:
Reactive

Group 18 (noble gases)



2 He Helium 4,01
10 Ne Neon 20,18
18 Ar Argon 39,95
36 Kr Krypton 83,79
54 Xe Xenon 131,29
86 Rn Radon (222,02)
118 Uuo Ununoctium (294)

Helium
Outer shell electrons:
2 (out of 2)
Protons in nucleus: **2**
How reactive relative to other elements:
Very unreactive

Neon
Outer shell electrons:
8 (out of 8)
Protons in nucleus: **10**
How reactive relative to other elements:
Very unreactive

Argon
Outer shell electrons:
8 (out of 8)
Protons in nucleus: **18**
How reactive relative to other elements:
Very unreactive

Krypton
Outer shell electrons:
8 (out of 8)
Protons in nucleus: **36**
How reactive relative to other elements:
Very unreactive

Xenon
Outer shell electrons:
8 (out of 8)
Protons in nucleus: **54**
How reactive relative to other elements:
Very unreactive

Radon
Outer shell electrons:
8 (out of 8)
Protons in nucleus: **86**
How reactive relative to other elements:
Very unreactive

Ununoctium
Outer shell electrons:
8 (out of 8)
Protons in nucleus: **118**
How reactive relative to other elements:
Very unreactive

TOXIC SCIENCE

Discover some of the deadliest substances known to humankind

Toxic substances include anything that can physically harm us after we inhale, swallow or touch it, from an innocent bee sting to full-blown cyanide poisoning. Defining toxicity is tricky since almost anything is poisonous at high enough doses – even water. Acute poisoning follows just one exposure, for example, nibbling a death cap mushroom, but chronic exposure – like inhaling cigarette smoke over decades – can be equally, if not more, damaging.

Toxins are toxic substances produced by living organisms. They use toxins mainly to ward off predators or paralyse prey. Small but deadly bacteria produce some of the most potent toxins known, including botulinum toxin A (Botox). Other toxic substances occur naturally on Earth, such as the hydrogen sulphide produced by volcanic eruptions. We humans have even invented man-made ones for use as pesticides, insecticides (eg DDT) or chemical weapons (eg sarin, VX).

Targeting different parts of the body, toxic substances can damage us in an alarming number of ways. Neurotoxins are some of the most effective, affecting the brain and nervous system and causing muscles to freeze or twitch uncontrollably. Other substances can burst our red blood cells or cause allergic reactions.

But not everyone is affected by toxic substances in the same way. How toxic a chemical is depends on how easily it is absorbed, metabolised and eventually expelled by the body. Children are generally more vulnerable as their bodies are not able to get rid of toxic substances as effectively. Different species are also more or less susceptible to various poisons – for example, it takes 1,000 times more dioxin to kill a hamster than a guinea pig.

Key

Toxicity: 1 – Unlikely to kill / 5 – Super-deadly
Rarity: 1 – Very common / 5 – Very rare

Botulinum toxin A (Botox)

This is the most toxic substance in nature: just one gram (0.04 ounces) could kill 14,000 people if swallowed – or 8.3 million if injected! Produced by Clostridium botulinum bacteria, this neurotoxin is responsible for botulism, a rare but life-threatening illness transmitted principally through contaminated canned food. Botulinum disrupts communication between nerves and muscle cells, gradually paralysing its victims and finally leading to respiratory failure. Extremely small doses of botulinum toxin can, however, be used to treat muscle spasms and excessive sweating and to paralyse the muscles that cause wrinkles (sold commercially as Botox).

The statistics...

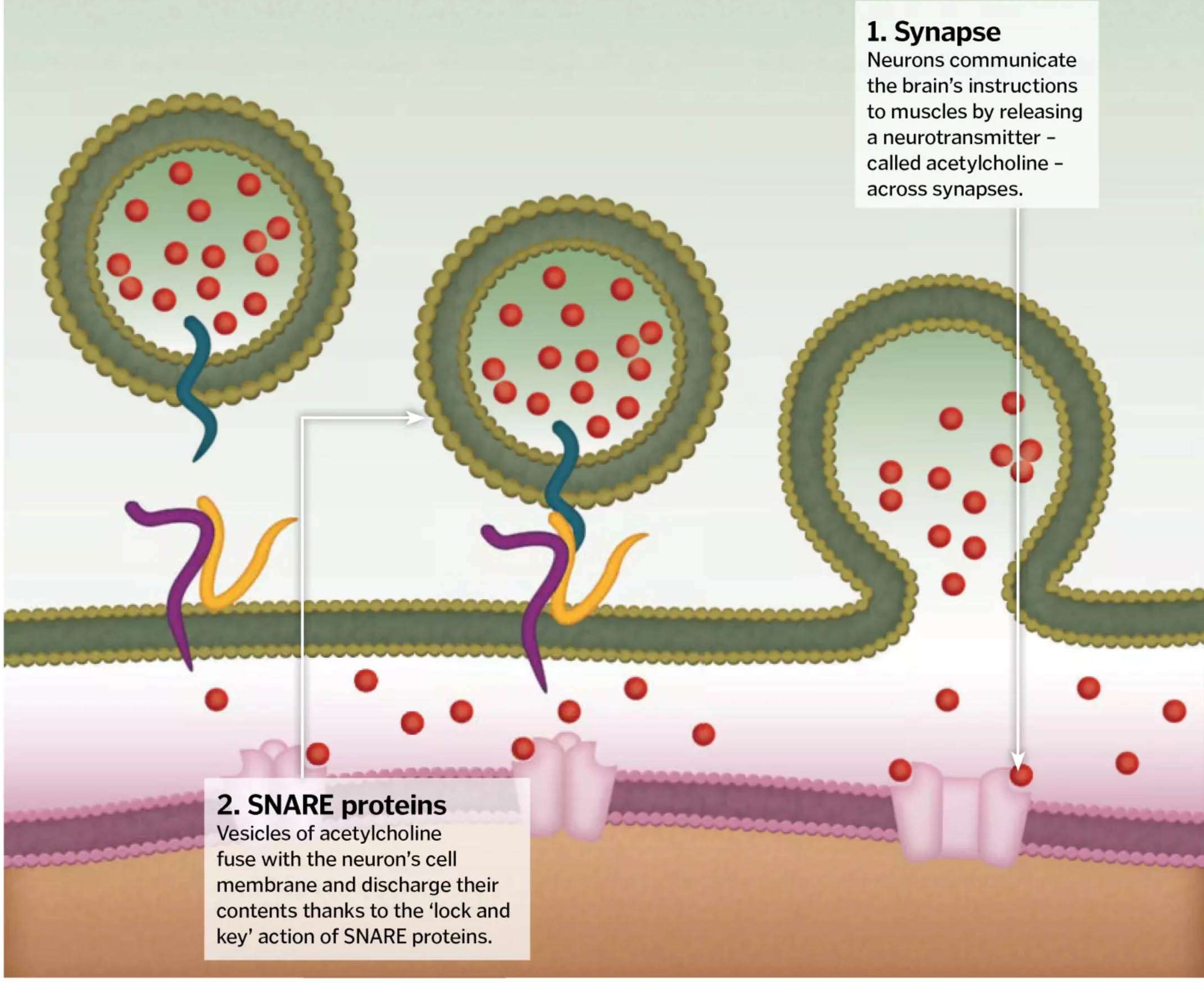
Main symptoms: Double vision, droopy eyelids, difficulty swallowing, slurred speech, muscle weakness, paralysis

Antidote: Horse-derived antitoxin

Time to death: Rarely fatal when treated

Toxicity rating: 5

Rarity rating: 4



5 TOP FACTS
TOXIC PLANTS

Castor oil plant
1 Listed by the *Guinness Book Of World Records* as the most poisonous plant on Earth, the ricin contained in one castor bean can easily finish off the average human.

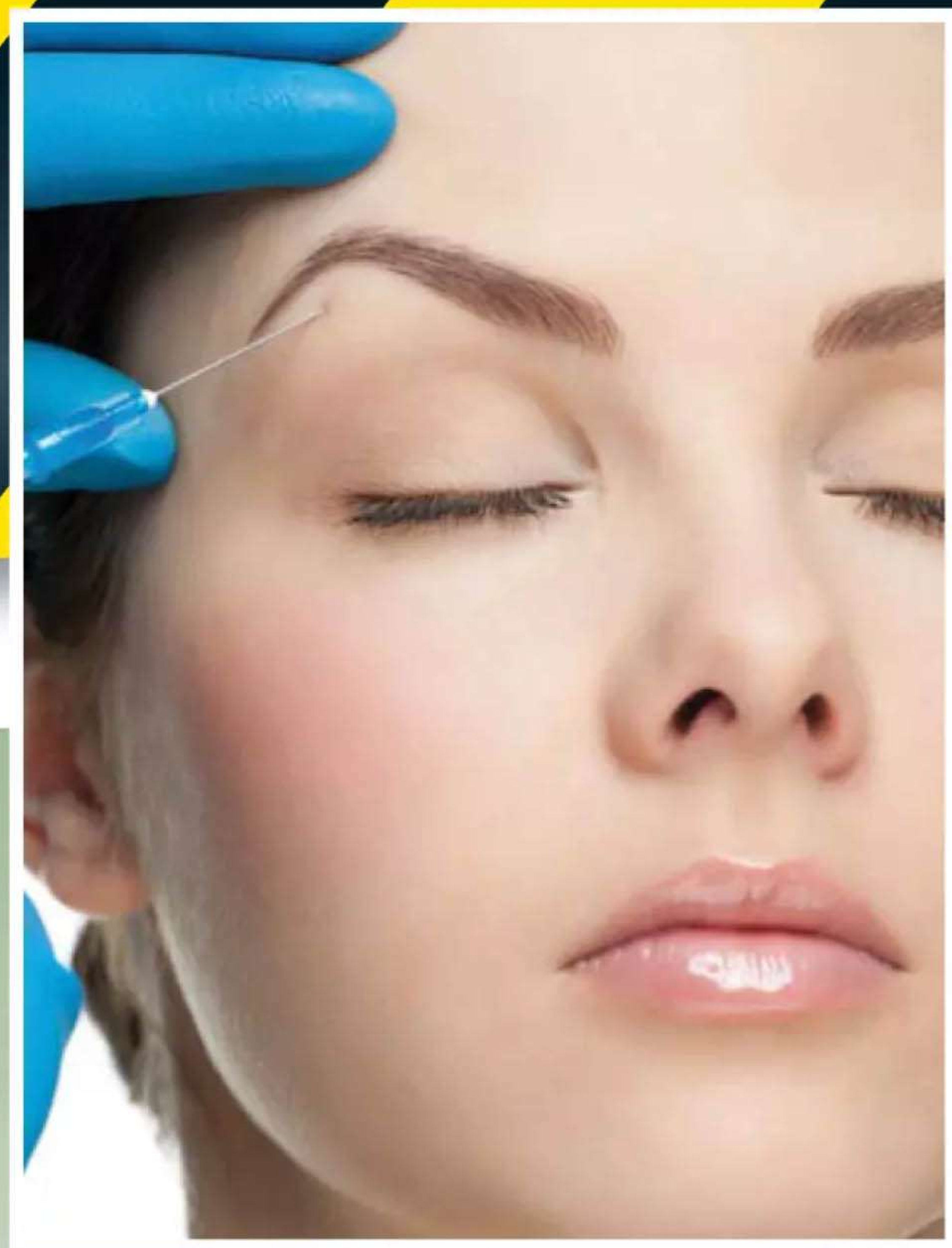
Oleander
2 Don't let its pretty blooms fool you – oleander contains potent glycosides which target the heart, provoking heart attacks in those who eat its flowers, leaves or fruit.

Rosary pea
3 The colourful seeds of Abrus precatorius are sometimes used to make jewellery, but they can poison handlers with abrin, a toxin which attacks protein-building ribosomes.

Belladonna
4 Also called deadly nightshade, this attractive plant contains a mix of alkaloids and was a popular poison in Ancient Roman times. Just one leaf is enough to kill a person.

Water hemlock
5 Native to North America, this plant contains cicutoxin, a neurotoxin which causes seizures, violent muscle contractions and loss of consciousness if ingested.

DID YOU KNOW? *Exposure to mercury in felt caused dementia in many 18th-century milliners – hence 'mad as a hatter'*



Asbestos

Asbestos is the name given to a handful of different minerals which share one common feature: bunches of fibrous crystals. Boasting an array of insulating properties topped off with a low price tag, asbestos was a popular building material until its toxic effects came to light. With repeated inhalation, asbestos fibres accumulate in the lungs, causing deadly diseases like asbestosis, an inflammatory lung condition, and cancer. These diseases typically don't develop until 15-30 years after exposure. Although now banned in most countries, older buildings can still release the harmful crystals when demolished.

The statistics...

Main symptoms: Shortness of breath, coughing, chest pain

Antidote: No current cure for asbestosis, but relief treatment

Time to death: Various

Toxicity rating: 4

Rarity rating: 3

Ricin

Found in the castor oil plant, ricin is a toxic protein that wreaks havoc on ribosomes, the cell's protein builders. The result is severe damage to major organs. Just one milligram of ricin is enough to kill an adult if inhaled or ingested, leading many countries to investigate its use as a biological weapon. The castor oil plant's popularity as an ornamental shrub and the relative ease of extracting the toxin from castor beans have also made ricin the poison of choice for many assassins.

The statistics...

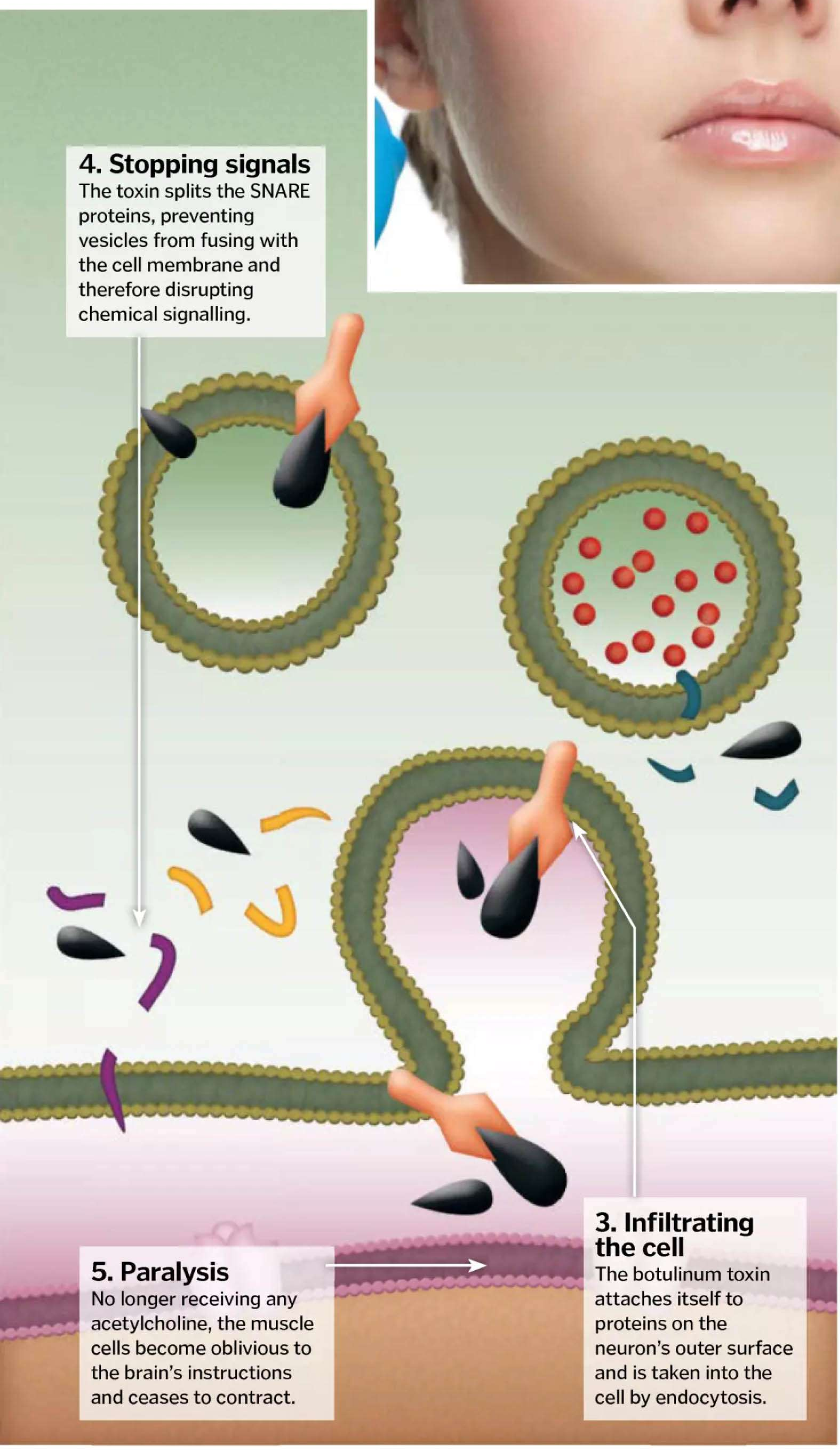
Main symptoms: Diarrhoea, nausea, accelerated heart beat, hypotension, seizures

Antidote: The UK military has developed an antidote, but it remains to be tested on humans

Time to death: 2–5 days

Toxicity rating: 5

Rarity rating: 2



Carbon monoxide

Colourless and odourless, carbon monoxide gas has a knack for going unnoticed. It is produced by the incomplete combustion of organic fuels including gas, coal and wood – occurring, for example, when inadequate ventilation deprives a gas-burning stove of oxygen. As a result, carbon monoxide poisoning is the most common type of air poisoning around the home. Carbon monoxide molecules bind tightly to haemoglobin, the oxygen-carrying protein in blood. Taking oxygen's place, they prevent blood from delivering oxygen to cells. You can reduce the risk by keeping your home well ventilated and servicing appliances such as boilers every year.

The statistics...

Main symptoms: Headache, nausea, vomiting, dizziness, fatigue, weakness, loss of consciousness

Antidote: Oxygen

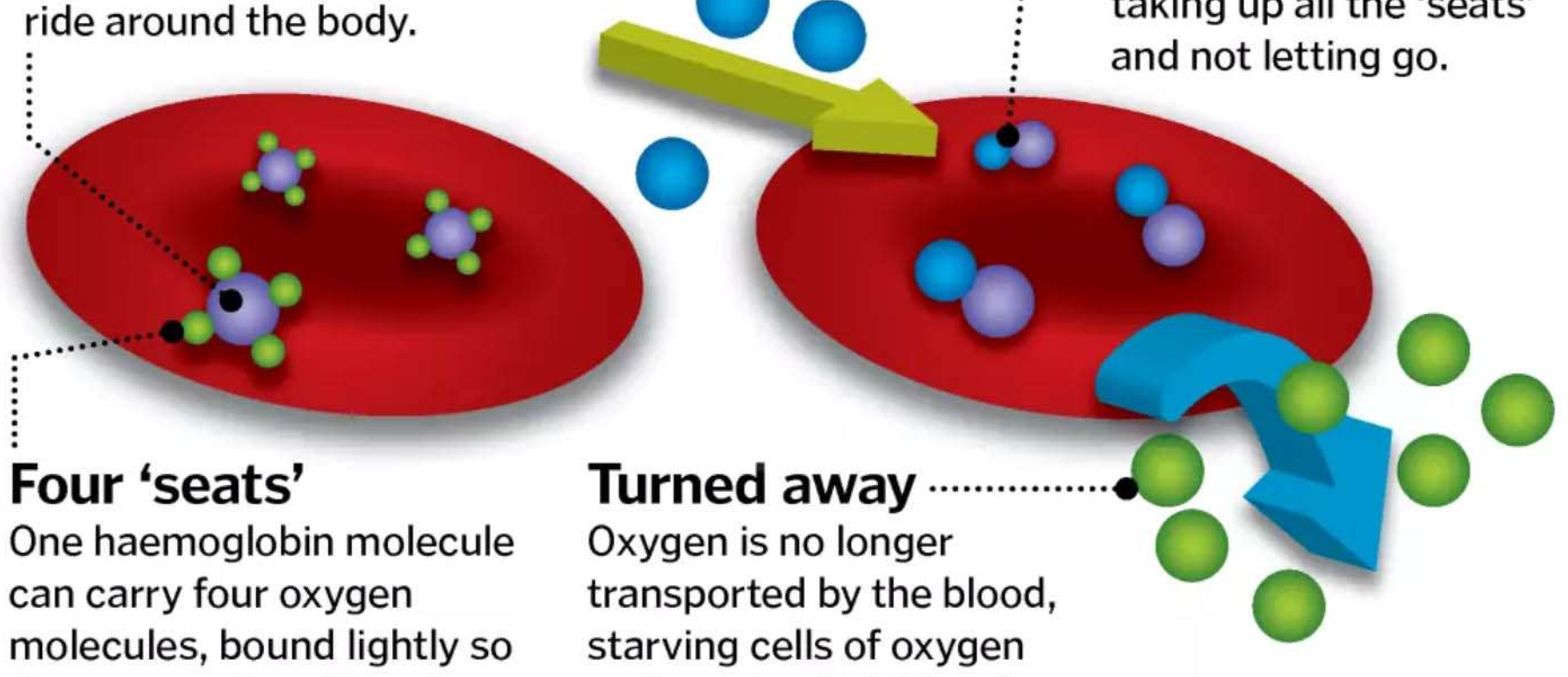
Time to death: 2-3 minutes in acute cases

Toxicity rating: 4

Rarity rating: 1

Haemoglobin
Oxygen binds with the iron atoms inside haemoglobin, hitching a ride around the body.

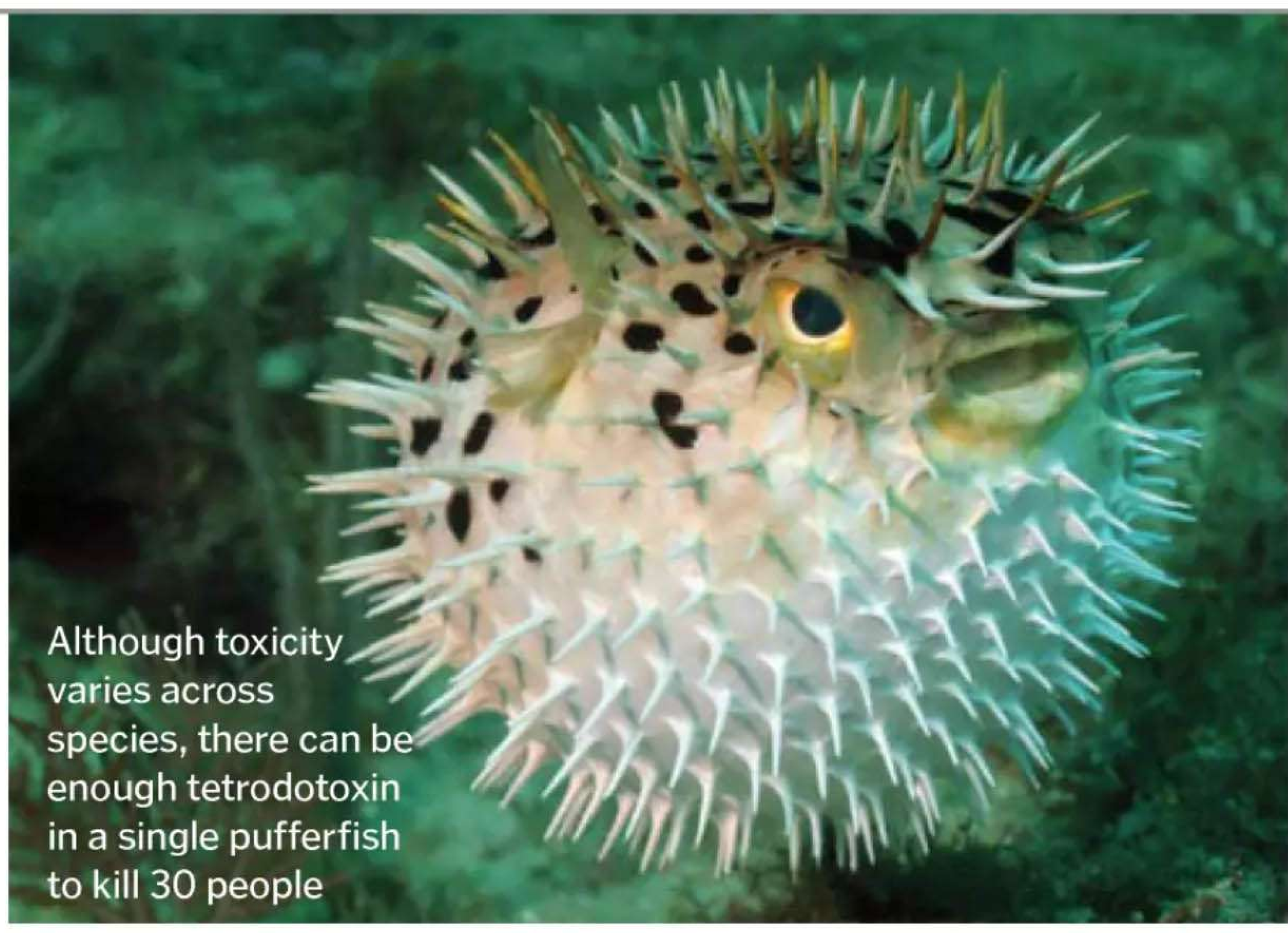
Carbon monoxide
Carbon monoxide binds to iron 200 times more strongly than oxygen, taking up all the 'seats' and not letting go.



Four 'seats'
One haemoglobin molecule can carry four oxygen molecules, bound lightly so they are easily released.

Turned away
Oxygen is no longer transported by the blood, starving cells of oxygen and eventually killing them.

"Although chefs need a licence to serve fugu, mishaps still poison an estimated 200 people each year"



Although toxicity varies across species, there can be enough tetrodotoxin in a single pufferfish to kill 30 people

Tetrodotoxin

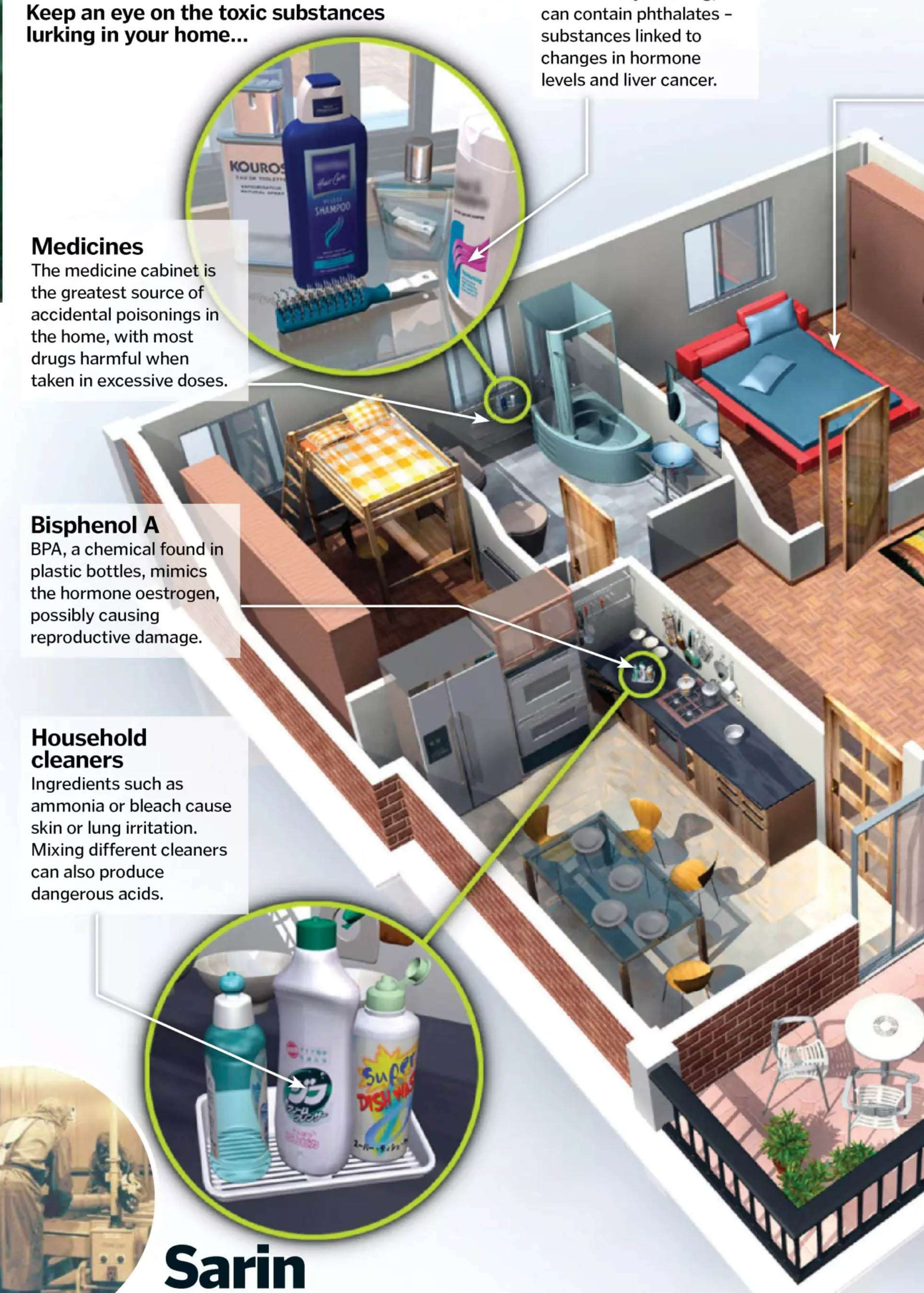
Thrill-seeking Japanese diners are sometimes tempted to try fugu, a variety of pufferfish. The catch? If the chef slips up, they risk being poisoned with tetrodotoxin, a potent neurotoxin contained in the fish's gonads, liver, intestines and skin. Opening nerves' ion channels, tetrodotoxin acts similarly to batrachotoxin to block nerve impulses, causing paralysis and death by respiratory failure. Although chefs need a licence to serve fugu, mishaps still poison an estimated 200 people each year, with half of them dying. Pufferfish are not the only ones to use tetrodotoxin; it is one of the most common toxins in the marine world, employed by scores of fish, crabs and molluscs, including the blue-ringed octopus.

The statistics...

Main symptoms:	Numbness of the lips and tongue, followed by paralysis that spreads to the entire body, heart failure
Antidote:	None known
Time to death:	4-6 hours
Toxicity rating:	4
Rarity rating:	4

Toxic household

Keep an eye on the toxic substances lurking in your home...



Phthalates
Personal care products, and also vinyl flooring, can contain phthalates – substances linked to changes in hormone levels and liver cancer.

Medicines
The medicine cabinet is the greatest source of accidental poisonings in the home, with most drugs harmful when taken in excessive doses.

Bisphenol A
BPA, a chemical found in plastic bottles, mimics the hormone oestrogen, possibly causing reproductive damage.

Household cleaners
Ingredients such as ammonia or bleach cause skin or lung irritation. Mixing different cleaners can also produce dangerous acids.

Cyanide

Whether inhaled or ingested, cyanide is one of the fastest-acting poisons known, sealing death sentences in minutes. Chemically speaking, a cyanide is a compound with a triple bond between a carbon and a nitrogen atom. Hydrogen cyanide gas and solid sodium or potassium cyanide are highly toxic, preventing the body's cells from using oxygen and starving the heart and the brain. Certain fruit pits contain cyanide and small quantities of hydrogen cyanide are present in engine exhaust fumes. Industrial uses include gold mining and pesticides – one of which was used by the Nazis in gas chambers.

The statistics...

Main symptoms:	Nausea, rapid breathing, dizziness, headache, convulsions – leading to death
Antidote:	In smaller doses hydroxocobalamin is one known antidote, but generally fatal
Time to death:	As little as a minute
Toxicity rating:	5
Rarity rating:	2

The statistics...

Main symptoms:	Constriction of pupils, drooling, difficulty breathing, loss of control over bodily functions, convulsions
Antidote:	Atropine
Time to death:	15 minutes to a few hours
Toxicity rating:	5
Rarity rating:	5

Sarin

Sarin is a man-made nerve agent, first developed as a pesticide by German scientists in 1938. A colourless, tasteless but extremely volatile gas, it works by inhibiting the body's enzyme which breaks down the neurotransmitter acetylcholine, causing it to accumulate at nerve endings. This signals to muscles to contract uncontrollably, triggering a range of unpleasant effects which culminate in death by asphyxiation. Like all chemical weapons, sarin is outlawed and has been used only a handful of times: like during the Iran-Iraq War in the Eighties, and in terrorist attacks on the Tokyo subway in 1995.

1. DEADLY

Taipan
Found in inland Australia, Earth's most venomous snake paralyses its victims with a powerful neurotoxin, usually killing in under 45 minutes.

2. DEADLIER

Golden poison-dart frog
The most poisonous of its family, this 2.5-centimetre (one-inch)-long amphibian has enough batrachotoxin to take out nine people!

3. DEADLIEST

Box jellyfish
This jellyfish's tentacles deliver a deadly blend of toxins simultaneously targeting the heart, nervous system, skin and red blood cells.

DID YOU KNOW? *Caffeine can be deadly – but only if you were to down about 90 cups of coffee in quick succession!*

Flame retardants
PBDEs (polybrominated diphenyl ethers) found in mattresses and furniture to make them fireproof may cause learning and memory deficits.

VOCs
Just after fitting, the glues and dyes used in new flooring can emit harmful volatile organic compounds (VOCs).

Carbon monoxide
Gas-burning fires can produce potentially deadly carbon monoxide gas if they don't receive enough ventilation.

Lead paint
Houses built before 1978 may contain neurotoxic lead-based paint which can be exposed if it peels.

Cigarettes
Smokers inhale over 700 poisons with each drag, including arsenic, benzene, cadmium, hydrogen cyanide, carbon monoxide and even radioactive polonium-210.

Garden chemicals
Exposure to pesticides, herbicides and fertilisers has been linked to asthma as well as various neurological, developmental and immunological disorders.

TCDD

TCDD is the deadliest of the dioxins. These chemicals occur in the natural world but are produced in much larger quantities by industry. Dioxins persist for a long time, accumulating in the fat cells of living organisms. As a result, small quantities of dioxins may go unnoticed, but over time they can damage the immune and reproductive systems and increase the likelihood of diabetes and cancer. High doses such as those experienced during the Vietnam War with the USA's use of Agent Orange – a herbicide contaminated with TCDD – spark an immediate reaction. They are also thought to cause cancer and birth defects years later, although TCDD's effect on the body is not yet fully understood.

The statistics...

- **Main symptoms:** Skin disease (chloracne) and discolouration, lung infection; in the longer term: cancer, birth defects
- **Antidote:** None
- **Time to death:** Unconfirmed
- **Toxicity rating:** 4
- **Rarity rating:** 2

Worst of the rest

1 Alpha-amanitin
This deadly toxin is taken up by the liver, where it inhibits an enzyme needed for cell division, causing liver failure.
Found in: Death cap and destroying angel mushrooms

2 Arsenic
Once believed to have killed Napoleon (now disproved), arsenic disrupts cells' energy transport, leading to organ failure.
Found in: Wood-preserving chemicals, insecticides

3 VX
VX is the most toxic nerve agent ever synthesised – ten times more toxic than sarin.
Found in: Russia and the USA – but now being destroyed

4 Strychnine
This poison causes some gruesome symptoms such as muscle convulsions, arching of the body and facial spasms.
Found in: Strychnos trees, rodent pesticides

5 Polonium-210
If ingested, this radioactive material bombards the body with deadly alpha particles.
Found in: Certain rocks, can settle on broad-leaf plants

Batrachotoxin

Batrachotoxin is the deadliest ingredient in a lethal cocktail of toxins secreted by certain poison-dart frogs. Native tribes use it as a weapon, dipping their blowgun dart tips in the frogs' toxins – these darts kill prey almost instantaneously. The frogs don't actually produce batrachotoxin themselves but obtain it by eating poisonous beetles. Batrachotoxin opens nerve cells' ion channels permanently, preventing them from creating an electric potential. This blocks cell signalling, paralysing muscles. Heart muscles are particularly sensitive to the toxin, leading to an irregular pulse and, soon after, a heart attack.

The statistics...

- **Main symptoms:** Convulsions, salivation, muscle contractions
- **Antidote:** None
- **Time to death:** Under 10 minutes
- **Toxicity rating:** 5
- **Rarity rating:** 4

Digitalis

Digitalis, or foxglove, owes its toxicity to cardiac the glycosides digitoxin and digoxin – compounds with the capacity to both help and harm. When ingested, glycosides affect the behaviour of heart muscles. In controlled doses, they can regulate the heart beat and treat congestive heart failure. But taking too much digitalis medication, or eating parts of the plant, can trigger a fatal heart attack; that said, eating foxgloves usually induces vomiting which prevents overdose. US serial killer Charles Cullen poisoned at least 29 elderly patients in nursing homes by administering overdoses of insulin and digoxin.

The statistics...

- **Main symptoms:** Nausea, vomiting, diarrhoea, visual disturbances, hallucinations, reduced heart rate
- **Antidote:** Digoxin Immune Fab: this binds to the toxin, preventing it from acting on the body
- **Time to death:** Rarely fatal but can kill in 24 hours
- **Toxicity rating:** 3
- **Rarity rating:** 2

“Launched in the Philippines in 2011, the project has brought solar bottle bulbs to 140,000 homes in the country”

Bottling light

Solar bottle bulbs are brightening up thousands of homes in the developing world, but how do they work?

Invented by Brazilian mechanic Alfredo Moser and developed with a little help from MIT students, a solar bottle bulb (or Moser lamp) is simply a soda bottle filled with chlorinated water, fitted into a roof. Refracting and reflecting sunlight downwards during the day, it lights up homes far more effectively than a skylight. Adding a few drops of bleach to the water ensures that it stays clean and free of germs for years. When sunlight meets the water in the bottle it slows down, bending (that is, refracting) downwards. Depending on its angle, some of this light is channelled straight into the room below while some rays hit the opposite side of the bottle and are reflected back in.

This phenomenon, known as total internal reflection, causes light to bounce back and forth inside the bottle until its angle is great enough for it to escape. As light exits the bottle at various directions, it illuminates the home just like an electric light bulb of about 60 watts.

What is the Liter of Light project?

The Liter of Light project, initiated by non-profit organisation MyShelter Foundation, aims to bring this sustainable, cheap, but life-changing technology to deprived communities across the world. Living in shantytowns where tightly packed dwellings let in very little natural light, many people are forced to live in near-complete darkness both day and night. Launched in the Philippines in 2011, the project has brought solar bottle bulbs to 140,000 homes in the country.

Total internal reflection can be used as a cheap and sustainable light source

Creating an effective light bulb out of a soda bottle is surprisingly simple

Making a bottle of light step-by-step

1. Materials
First you need a 1.5-litre PET plastic bottle, a piece of corrugated iron, some rubber sealant, filtered water and bleach. You'll also need cutters to slice through the iron sheeting, sandpaper, a drill and rivets to fix the bottle. This is an adult-only project.

2. Cut
Trace two concentric circles onto the iron sheet: one with the same diameter as the bottle and one a centimetre (0.04 inches) smaller. Cut out the inner circle then make small incisions radiating out. The resulting strips will provide a snug fit for the bottle.

3. Stick
Sandpaper the upper third of the soda bottle to give the sealant a better grip. Then slide the bottle into the corrugated iron so that the smooth upper third sticks out at the very top. Glue firmly into place using the sealant and allow time to dry completely.

4. Fill
Fill the bottle with water, adding 10 millilitres of bleach before screwing on the cap. Mixed with water, the chlorine in bleach forms hypochlorous acid (HOCl). Breaching micro-organisms' cell walls, this damages cell proteins and prevents murky water.

5. Install
Cut a hole in the roof just slightly larger than the bottle's diameter and apply sealant. Push the base of the bottle through and make sure it is firmly in place. Drill holes into the roof on each side of the bulb and secure with rivets. Apply sealant to avoid leaks.

5 TOP FACTS FROZEN GOODS

Medical uses
1 The process of freeze-drying is not only used for prolonging the shelf life of food. It's also used to preserve tissues such as blood plasma and to concentrate solutions.

Ancient history
2 Ancient Peruvian Incas used to store their crops in the Machu Picchu Mountains. The low air pressure, high altitude and cold air vaporised the water in the crops.

Spot the difference
3 Freeze-drying differs from dehydrated products because they are made using low heat, while dehydrated foods' moisture is removed through evaporation.

Correct storage
4 The secret to maximising the life of freeze-dried food items is storing it out of direct sunlight, at a cool temperature and away from potential water spillage.

Lightweight
5 Once food has undergone the freeze-drying process, it weighs 75-90% less than its original weight. This makes it ideal for emergency kits as it takes up less room.

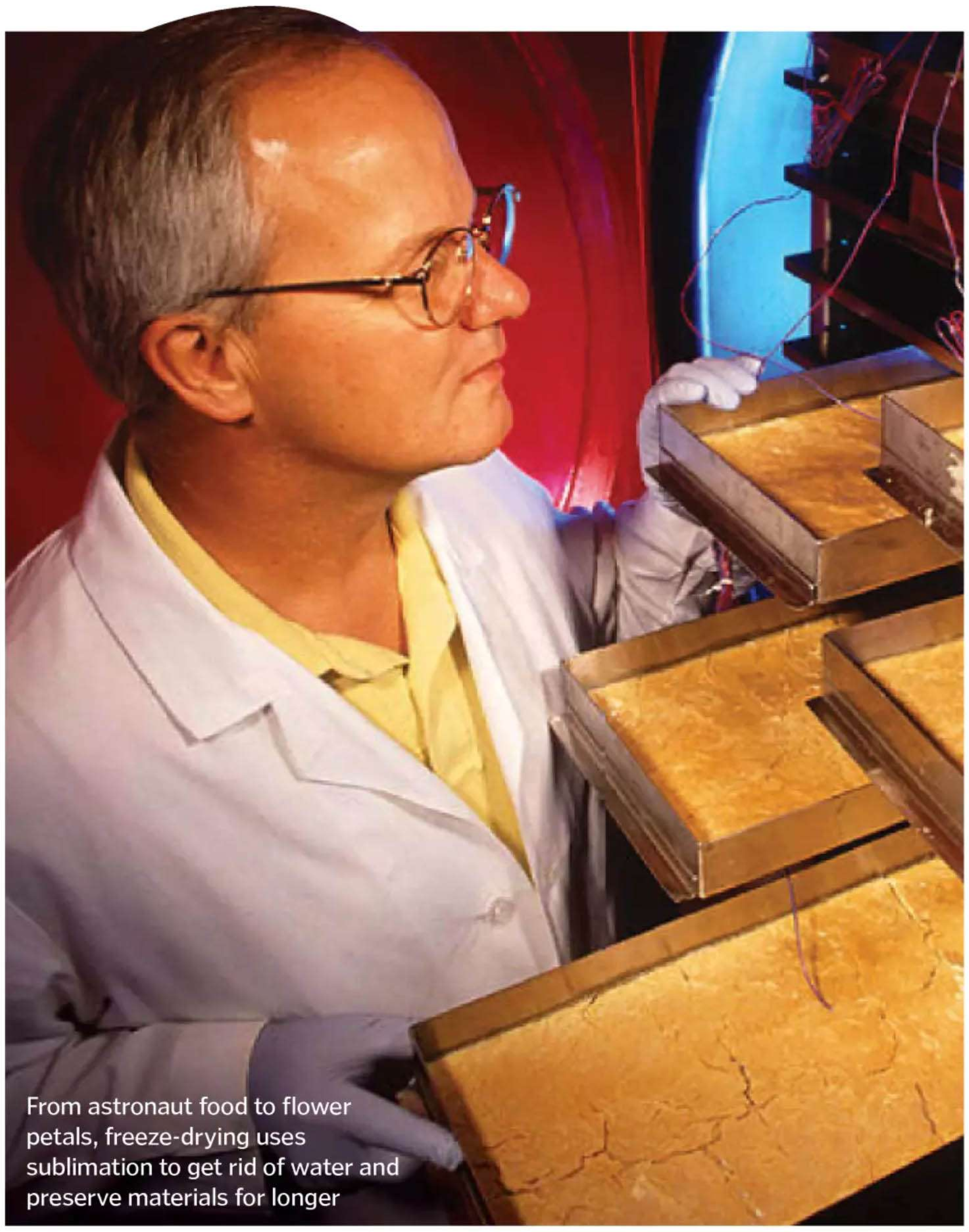
DID YOU KNOW? *The shelf life of freeze-dried food is an astounding 25 years!*

How freeze-drying works

Why does this simple process stop food and pharmaceutical goods from perishing?

The micro-organisms that degrade food, medicines or biological samples all need water to survive. By eliminating almost all water, freeze-drying (formally known as lyophilisation) increases the shelf life of these products dramatically. What's more, unlike traditional dehydration methods, freeze-drying preserves the structure of foods, meaning it has less of an effect on the taste and texture once the item has been rehydrated.

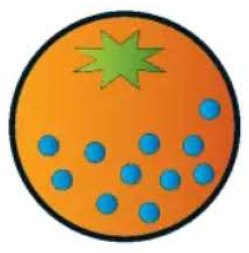
The secret to freeze-drying is turning ice directly into water vapour – without going through the liquid phase – a process called sublimation. First the material to be preserved is frozen. The freeze-drier then drops the air pressure, lowering the boiling point of water. A slight increase in temperature then provides the ice molecules with enough energy to break free from their bonds to form a vapour. This process removes almost all the water from the material to be preserved, without affecting its structure.



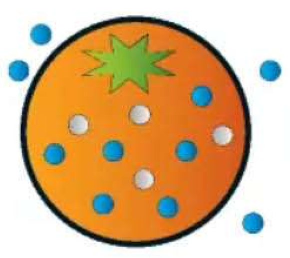
From astronaut food to flower petals, freeze-drying uses sublimation to get rid of water and preserve materials for longer

Freeze-drying step-by-step

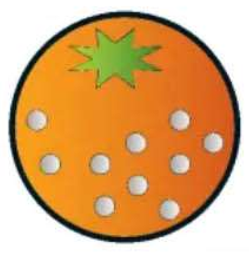
We take you through the key stages of preserving food



1. Freezing
The food is rapidly frozen at very low temperatures to avoid the formation of large ice crystals that could damage its structure.



2. Sublimation
Decreasing the pressure and then increasing the temperature allows the water to sublimate, passing directly from a solid state to a vapour.

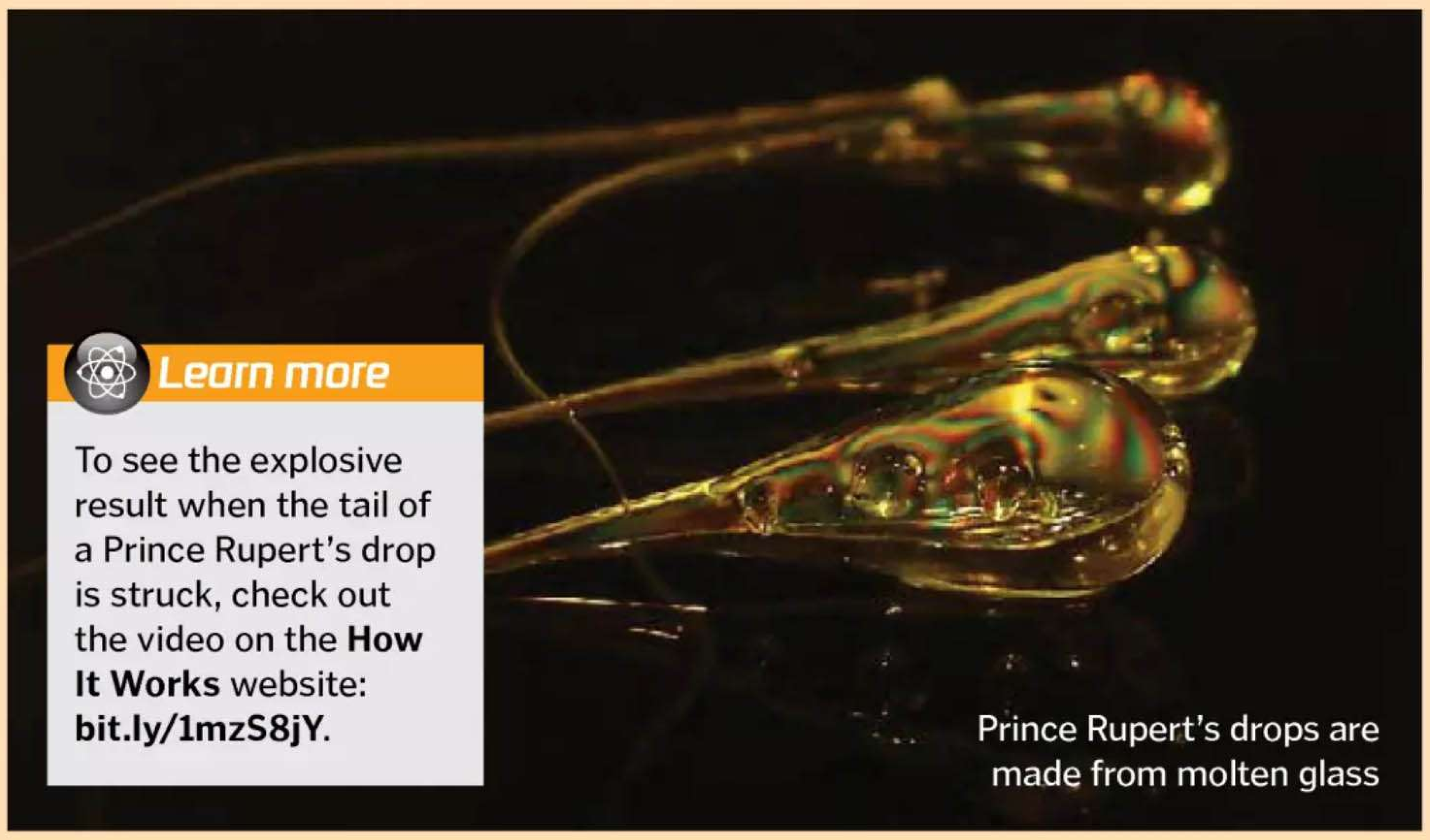


3. Dried product
Containing one to five per cent of its original moisture content and sealed in moisture and oxygen-proof packaging, it can be kept for years.

4. Rehydration
Certain freeze-dried foods (including fruits such as apples) can be eaten as is. Others are restored to their original form by adding water.

What are Prince Rupert's drops?

Find out why these glass globules are simultaneously tough as nails yet prone to shatter

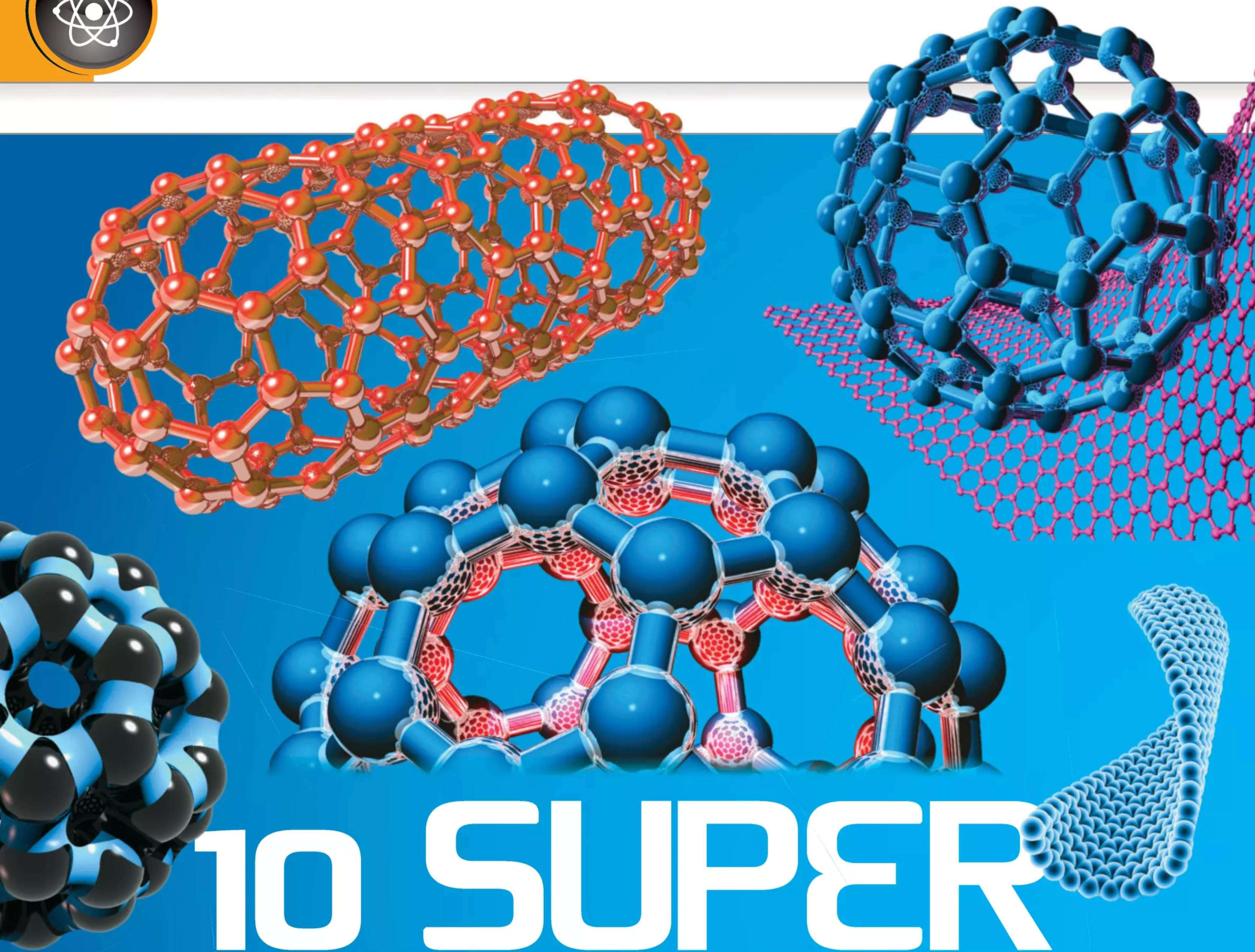


Learn more

To see the explosive result when the tail of a Prince Rupert's drop is struck, check out the video on the **How It Works** website: **bit.ly/1mzS8jY**.

Prince Rupert's drops are made from molten glass

Hit the head of a tadpole-shaped Prince Rupert's drop (aka Dutch tear) and it seems pretty tough. But tap its tail lightly and the whole thing shatters in a cloud of glass fragments. Prince Rupert's drops are made by pouring molten glass into cold water. The outside of the glass cools and solidifies very quickly, forming a hard casing. The centre shrinks as it gradually cools, but the solid outer shell cannot mould itself to this new shape. This results in a great deal of internal stress as the centre of the drop pulls the outside inwards. This tension makes the tail vulnerable to even the tiniest of cracks, which can spread along the drop's full length in under a millisecond as the built-up stress is released. Curiously, the same structure makes the head of the drop super-strong (ie it can survive a hammer blow) since the internal stress keeps it tightly compressed.



10 SUPER MATERIALS

How are we enhancing Mother Nature's design to develop the new-and-improved materials tomorrow's world will be made of?

With natural resources dwindling and some no longer meeting our needs, a new range of 'super materials' are now being developed in labs around the world. Designed to increase efficiency, these substances are new compounds that build upon and improve what's currently available, to be the best in a particular field.

Natural materials have been used for decades and even centuries to perform many day-to-day tasks, from conducting electricity to insulating heat, but super materials take things to a whole new level. The emphasis is now geared towards the best and only the best. Nothing less than total conduction, extreme strength or complete insulation will do. Essentially these materials will do the job better than anything that has gone before.

Whether it's based on an existing natural substance or an improvement on previous man-made efforts, super materials look to become increasingly important in a world searching for sustainable and greener energy sources. However, many questions still remain. Can we harness these materials and mass-produce them? Will they be available to the general public? Are they as good as they seem?

Over the following pages we present our pick of ten of the most impressive super materials that look set to reshape our future.

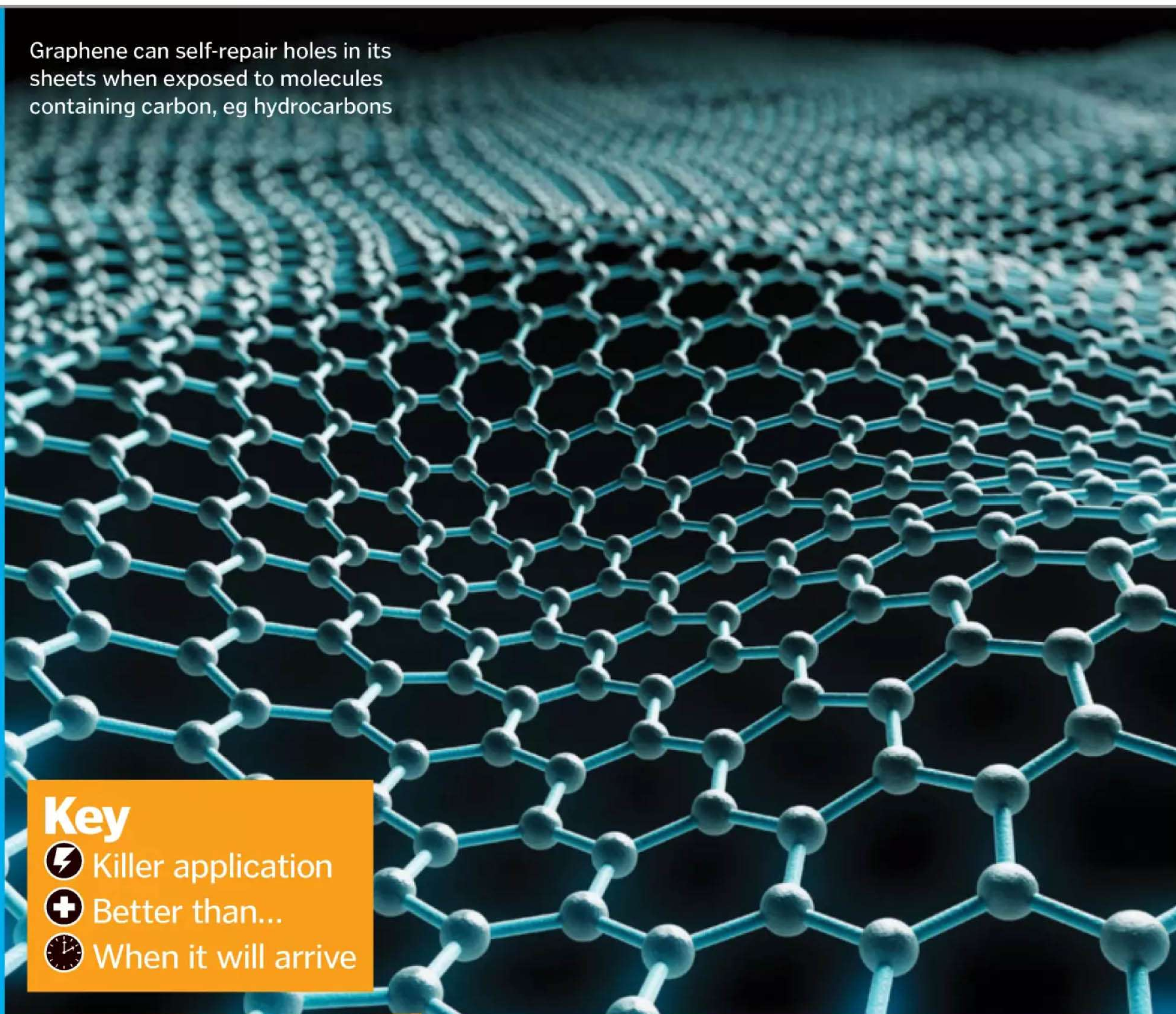
STRANGE BUT TRUE
SILKY SITUATION

What makes spider silk so difficult to mass-produce?

A The silk breaks easily **B** The spiders eat each other **C** Most spiders are stuck in a bathtub

Answer:
Unlike silk worms, spiders are cannibals so will eat their own if put together to produce silk. They can't be effectively farmed, as it takes hundreds of them to make even small amounts of cloth.

DID YOU KNOW? *Diving beetles have hydrophobic hairs that enable them to trap a layer of air under their wings*

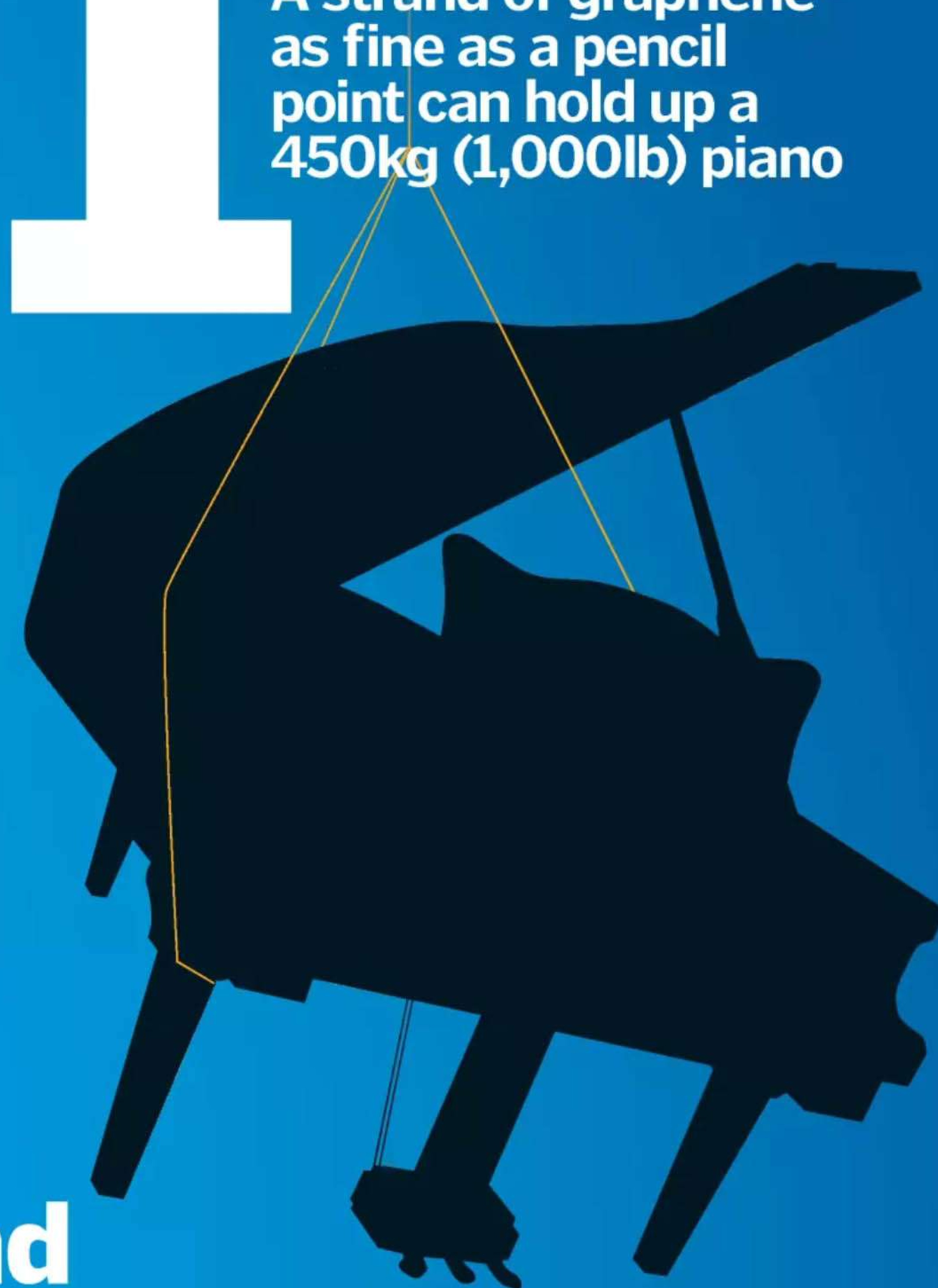


Graphene can self-repair holes in its sheets when exposed to molecules containing carbon, eg hydrocarbons

Key
- Killer application
- Better than…
- When it will arrive

1 grand piano

A strand of graphene as fine as a pencil point can hold up a 450kg (1,000lb) piano



GRAPHENE Stronger than diamond

If super materials had a poster boy, graphene would be it. Composed of a single layer of graphite carbon atoms in a honeycomb pattern, its structure is stronger than diamond. It was first theorised as far back as the mid-20th century but only gained recognition for its astonishing properties when Andre Geim and Konstantin Novoselov experimented with it and went on to claim a Nobel Prize in 2010.

Graphene is famed for its excellent conduction of both heat and electricity. Atomic force microscopy has proved it is, at the very least, 100 times stronger than steel and can be stretched by up to 20 per cent of its own size. It has been used for all manner of things, such as a coating material to nullify lightning strikes, increasing energy storage in batteries and making touchscreens more responsive.

Its coating properties in particular help stop corrosion and prevent micro-organisms from spreading. The electrons within it travel at a hundredth the speed of light as if they carry no mass. Graphene's tiny size makes it ideal for small electronic devices, as its high thermal conductivity enable them to dissipate heat while still maintaining power.

Graphene is also actually the source of many other super materials and is the parent form of carbon nanotubes and buckyballs. However, it was only experimentally isolated on its own accord in the 2000s by the aforementioned Nobel Prize winners.

There are currently only a few ways of producing graphene: mechanical or thermal exfoliation, chemical vapour deposition and epitaxial growth. None of these methods are exactly geared for production on a large scale, so a new way of creating the super material has been proposed. This involves oxidising the graphene that turns it into graphene oxide, which is easier to contain and transport. However, this method is still in its early stages.

Adding this simple carbon allotrope to a variety of surfaces and devices is surely the future as the human race looks to establish ever-more efficient materials. Some are sceptical of the potential of this substance and it's admittedly hard to believe that one material can have so many impressive properties, but graphene undoubtedly still has much to offer.

- Counteracting lightning strikes
- Copper wires at conducting electricity
- Already around, with its uses increasing

Five ways we can use graphene

1. Lightning catcher
Outstanding electrical conductivity means it can not only nullify lightning, but perhaps even harness it. This has never been done, but graphene could be the material for the job.

2. Wires
Copper wires are found in all electrical circuits, but graphene can transport 1,000 times the density of copper. Increasing electrical efficiency would cut emissions and fuel use.

3. Coatings
Graphene is useful at creating composite materials and can coat plastics or metals to improve their properties, such as electrical conduction or strength.

4. Touchscreens
Handy for touchscreens on smartphones and tablets, graphene is transparent and can transmit 97.7 per cent of light. Its strength also sees off scratches while keeping flexibility.

5. Bio-engineering
Experts suggest the material could have the capability to monitor glucose and cholesterol levels, as well as aid tissue rejuvenation and even cancer treatments.


Another type of natural plastic called coleoptera is made of beetle shells; inset is an example of shrilk

SHRILK

The next generation of plastics

Composed of silk proteins and shrimp shell, shrilk combines biodegradability with excellent flexibility and strength. Based on similar substances in the animal kingdom, shrilk's roots lie in the material found in shells and insect wings. The hope is that the material can replace plastic, which would lessen the impact and size of landfill sites. Like plastic, it's inexpensive and can be used to make clothing, bags and many other everyday products.

In addition to shrilk, there has also been progress with another plastic formed from dead beetle shells – known as coleoptera. This contains chitin, a natural polymer that boasts the light weight and flexibility of conventional plastics but breaks down far more easily.

Shrilk and other biodegradable plastics are great examples of where the fields of biology and engineering create the ultimate material solutions.

- Potential to replace plastic
- Lighter than aluminium and equally strong
- More research needed to be mass-produced

Strongest magnet in the world

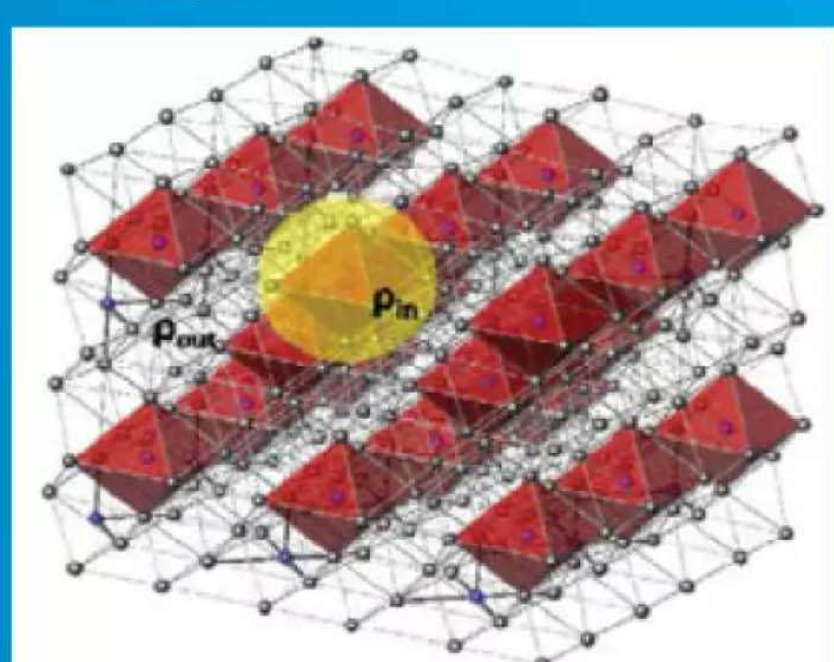
IRON NITRIDE

The most magnetic material on Earth is a mix of iron and nitrogen with the chemical symbol $Fe_{16}N_2$. It's claimed that the material has the strongest saturation magnetic flux density of any man-made substance. This means that the strength of magnetism is the most per unit of molecule within the iron nitride, making it hugely magnetic over its entire surface. Powered by ferromagnetism, iron nitride is electrically uncharged but that doesn't affect its power.

Every electron within the material acts like a tiny magnet. The Fe-N clusters increase electron contact, which intensifies the charge. It's so magnetic that it exceeds the predicted limit of magnetism for a single material. Iron nitride has taken over from the previous holders, neodymium and iron cobalt, to claim the plaudits for the most magnetic material on Earth. It's at least twice as magnetic as its rivals (rated at 130 megagauss oersteds).

Magnets of this magnitude are used in industry and engineering to increase the efficiency of power-production. They are often used as electromagnets within transformers, for example.

- Making disk drives more effective
- Neodymium and iron cobalt
- Still in the testing stages – watch this space



"High magnetic fields play a critical role in developing new materials that affect nearly every modern technology. The vast scope of work currently underway includes the study of new superconductors with the potential to revolutionise how power is stored and delivered. There's also a search for new medicines and analysis of petroleum samples that could lead to better oil extraction"

Greg Boebinger, director at the National High Magnetic Field laboratory, Florida State University

STANENE

The perfect conductor

Composed of a single layer of tin atoms, stanene is said to be able to conduct electricity with 100 per cent efficiency at room temperature.

This astonishing electrical conductivity has seen it dubbed by some as the new graphene and it's expected to play a big role in the future of computer chips.

Stanene is part of a group of topological insulators that conduct electricity only on their outer edges. Being only an atom thick, the electrons can travel through the material with no resistance, which improves efficiency. However, stanene is the first of these topological insulators to work at room temperature. Difficult to produce due to its minuscule size, the material is still in the developmental stages. There's also talk of adding in a layer of fluorine to increase conduction efficiency at higher temperatures as well.

- Boosting the processing speed of computer chips
- Potentially even graphene
- Far from wide-scale production

AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

Graphene: journey to the super material king

www.howitworksdaily.com

DID YOU KNOW? *Nanotubes could theoretically be used to make an Earth-to-orbit space elevator*

SUPER-HYDROPHOBIC MATERIALS

The hydrophobic qualities of plants like nasturtiums have been applied to glasses in traffic control units, medical slides and circuit boards (inset)

Completely waterproof

Man-made waterproof materials have paled in comparison with natural examples such as the lotus leaf and insect wings – until now. Known as the most waterproof material ever, super-hydrophobic surfaces have been developed at the Massachusetts Institute of Technology (MIT) and are inspired by butterfly wings and nasturtium leaves.

Often referred to as the lotus effect, nature's waterproof materials defend themselves from water through a special structure. They are covered by bumps or hairs that when exposed to liquid can direct it away from the body. Various man-made materials have taken advantage of this technique, including synthetic silicon, polymer microposts and electro-deposited copper. These coatings, like the organic inspiration, enable water droplets to bounce off a surface to keep it dry. The materials have small ridges that break up the water on the surface and disperse it before it can soak through.

Some of these materials are being pushed even further, with efforts to make them repel ice and snow too. Hydrophobic materials are perfect for everything from clothing to tents and vehicle coatings.

- A de-icer that will rapidly clear snow and ice
- Lotus leaves have finally been surpassed
- Already available in clothing and more

"To be super-hydrophobic, a material requires both hydrophobic chemistry and roughness. The trapped layer of air, under certain situations, may act to reduce the drag on an object passing through water"

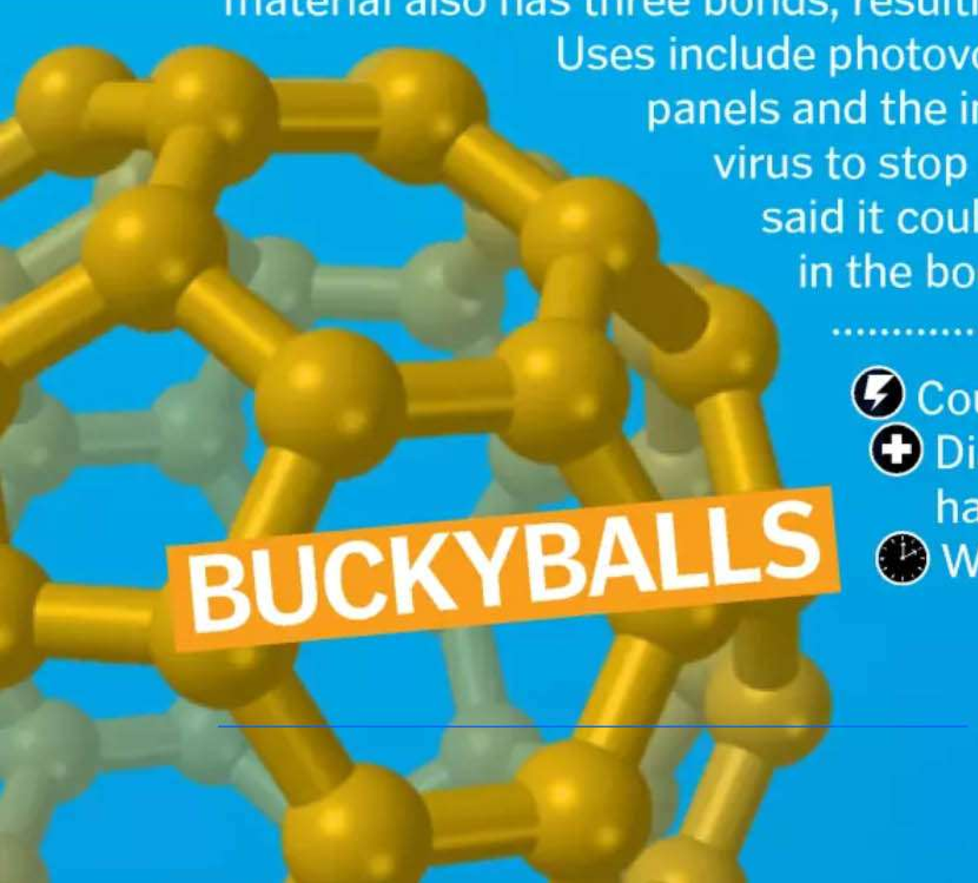
Michael Newton, Nottingham Trent University

The original super material

Affectionately known as buckyballs, buckminsterfullerene is one of eight carbon allotropes that include diamond, graphene and carbon nanotubes. Discovered by accident, buckminsterfullerene can be considered the daddy of super materials. Its discovery paved the way for the modern era of nanotechnology and proved that materials with extreme properties could be found and worked on. It has led to the discovery of carbon nanotubes as scientists were encouraged to enhance carbon allotropes further in the search for the next carbon nanomaterial.

The allotrope is shaped a bit like a football, with a hexagonal and symmetrical polyhedral structure. A tough skeleton of 60 carbon atoms makes buckminsterfullerene even stronger than diamond under certain conditions. Every carbon atom within this super material also has three bonds, resulting in its incredible strength. Uses include photovoltaic applications in solar panels and the inhibition of a protein in the HIV virus to stop it replicating. Some have even said it could limit oxidative stress of cells in the body that cause ageing.

- Could combat HIV and cancer
- Diamond when tested for hardness under high pressure
- Widely used since 1985



BUCKYBALLS

"Superglue is a polymer-based adhesive of the cyanoacrylate type that is polymerised upon contact with a surface and moisture. Some of the uses of these adhesives can be in the form of coatings, fillers, forensics, or even for medical uses like closing [open] wounds"

Rigoberto Advincula, professor of macromolecular science and engineering at Case Western Reserve University, OH, USA

MOLECULAR SUPERGLUE

Most adhesive glue

First there was glue, then there was superglue, but now there is molecular superglue. From the cyanoacrylate (instant glue) family of adhesives, it is designed to be the most adhesive material on the planet and will primarily be used to fight disease.

Genetically engineered from proteins, the glue is polymer-based and formed from nanotechnology that bonds molecules together to form tough covalent bonds. The technology enables the protein to react with itself to form a tight lock. Most effective when used thinly, the glue is made from the proteins of the streptococcus pyogenes bacteria, enabling it to hook on to human cells.

Even more impressive, the glue can be designed to be selective to what it sticks to. This is essential, as an adhesive this strong would cause havoc if it got stuck to the wrong objects!

- Closing up wounds in seconds
- Any previous superglue – and a whole other league to PVA glue
- Here now, but its uses are not fully confirmed

Solids that are lighter than air

Created by removing liquid from a gel, aerogels are the world's lightest solid materials. High in strength and low in density, they are mesoporous, which means they contain lots of tiny pores, contributing to their low density. There are various types of aerogels, all with different functions and abilities.

First, silica aerogels have an extremely low thermal conductivity and can be used as super-insulators. The most common of the gels, these have even been used on expeditions to Mars.

Carbon aerogels can store high amounts of energy and are ideal as fast-charging super-capacitors. They are predicted to be used as a new type of faster charging and discharging battery in mobile phones and electric cars.

Lastly, metal aerogels combine the properties of the two substances. Being highly conductive and having a high surface area, X-ray optics and hydrogen storage are just two of the possible functions for this hybrid material.

- Protection in firefighter suits
- Surpasses all other heat insulation
- Currently used, but development continues

7x lighter than air

Aerogels are so light a flower or seed head can support them

AEROGELS

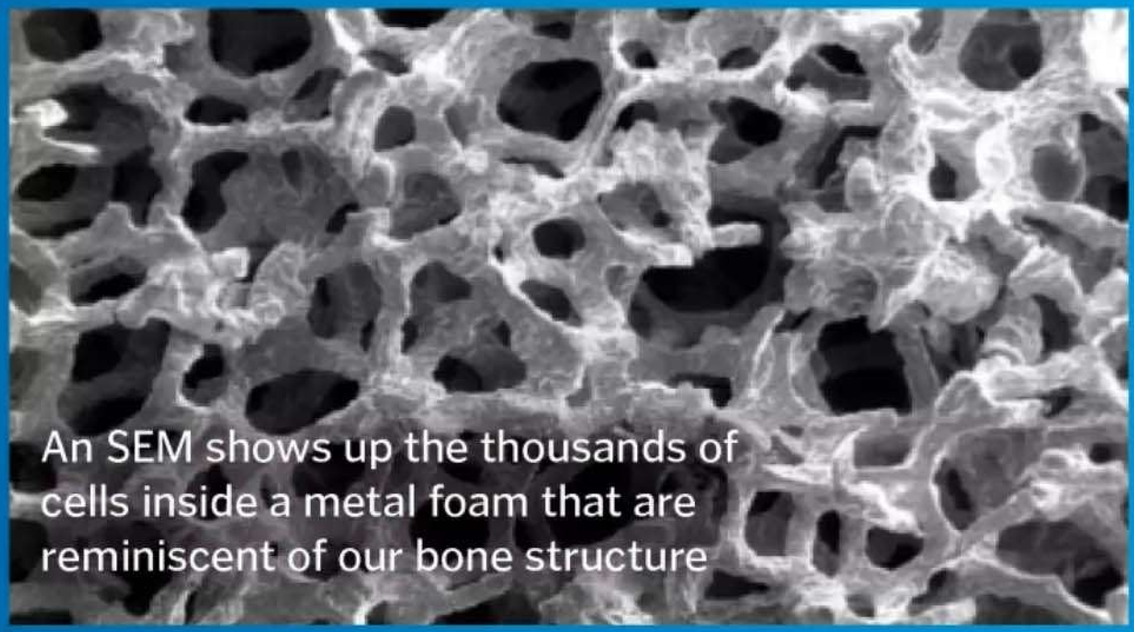
TITANIUM FOAM

The metal that can replace bone

Metal foams are generally solid metals filled with tiny holes, known as 'cells', and up to 95 per cent of their volume can be air. Their biggest selling point is that while they are light and porous, they retain much of their original strength. Made from a mix of metal powder and polyurethane, a binding agent fixes the two substances together under heat.

Titanium foam in particular is tough but at the same time has very similar properties to bone. Experts predict that bone will be able to naturally regrow around it, making this material a very attractive prospect for mending breaks and fractures. Also corrosion-resistant, it can endure nearly all chemicals, making it useful not just as a biocompatible material in the body but also for aerospace components.

- Currently used on drones and lightweight aircraft
- Many metals used in construction
- Expected to be used in bone-reconstruction as soon as research confirms its viability



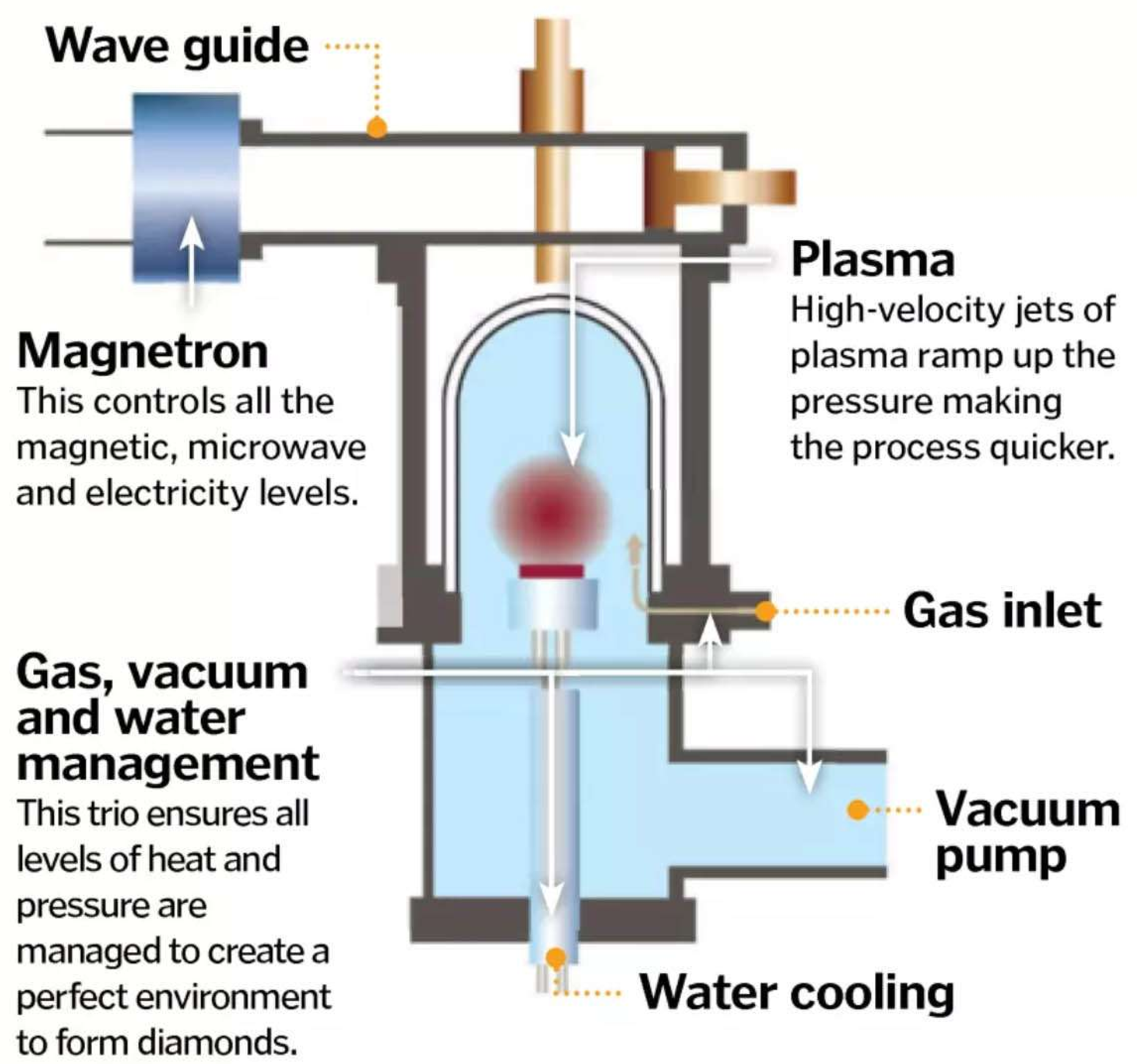
An SEM shows up the thousands of cells inside a metal foam that are reminiscent of our bone structure

"Titanium is light, strong and, most importantly, corrosion-resistant. The most vital application of titanium foam is as artificial bones, because it can be tailored to have similar mechanical properties to human bones and the porous structure is conducive to ingrowth of tissue cells"

Yuyuan Zhao, head of the Centre for Materials and Structures, University of Liverpool

Make your own diamond

Famed for their beauty and toughness in the natural world, diamonds are becoming increasingly rare. Steve Coe, from synthetic diamond manufacturer Element Six, takes us through two ways they're re-creating these gems for drilling, optics, acoustics and more.



Chemical vapour deposition

Chemical vapour deposition (CVD) uses a hydrocarbon gas mixture, where the diamond is produced in a vacuum system below atmospheric pressure, with carbon atoms supplied from a gas such as methane and deposited in layers onto a substrate.

By passing microwaves through the gas to generate a plasma, at temperatures around 2,000°C (3,632°F), atomic hydrogen is created, enabling impurities in the form of graphite to ensure only the diamond carbon is deposited.

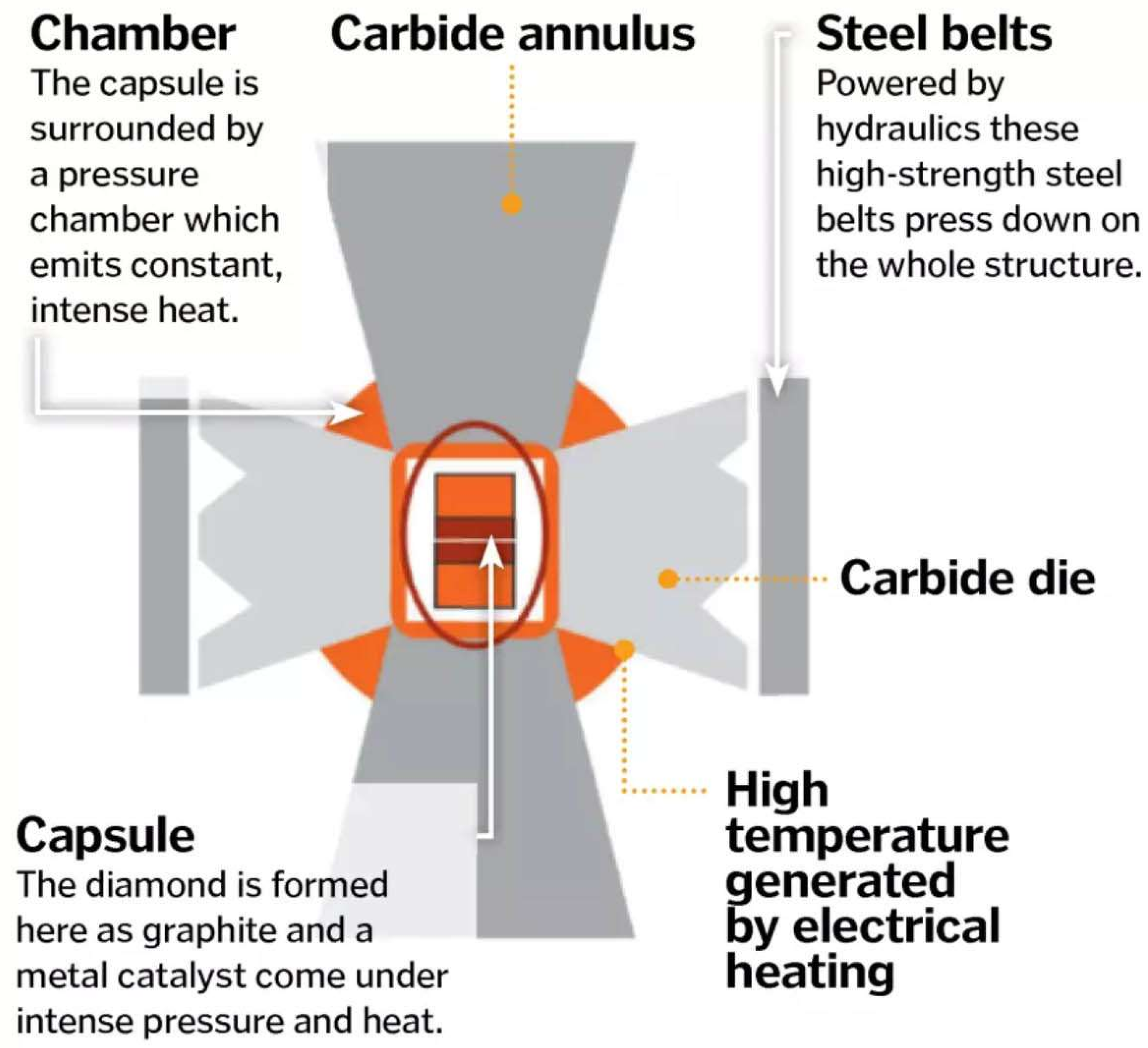
This technique enables tightly controlled growth conditions, eliminating impurities and enabling the engineering of various properties into the diamond material.

High-pressure high-temperature diamond synthesis (HPHT)

This is a synthesis process by which synthetic diamond is created under enormous pressure and temperatures to replicate the Earth's natural process.

The proprietary belt-press technology contains two large anvils to apply hydraulic force to a capsule at the centre.

This capsule contains graphite and a metal catalyst, which react during the process to form diamond. The 15,000 atmospheres of pressure applied to the capsule is the equivalent of taking the Eiffel Tower, inverting it and placing it on a soda can, then turning the temperature up to 1,500°C (2,732°F) – the melting point of steel.



5 TOP FACTS
MATERIAL MARVELS

Plastic
1 First created in the late-19th century, plastics still play an essential role in manufacturing and industry on almost all levels of industry across the globe today.

Safety glass
2 Made in the early-20th century, a thin layer of plastic is added to glass so it doesn't shatter or splinter, making ever-taller buildings much safer than before.

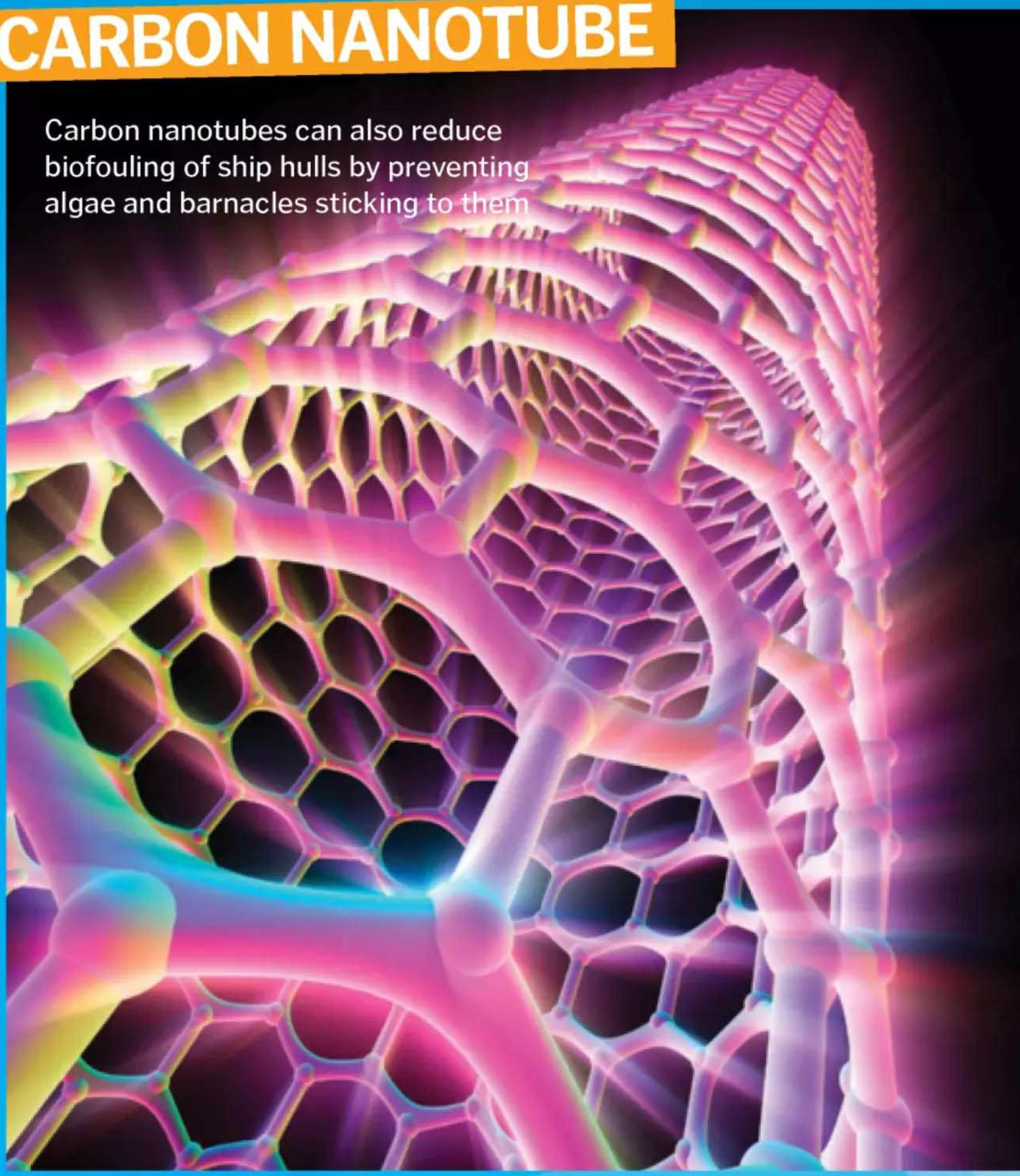
Stainless steel
3 Originally called rustless steel, the new type of steel formed a passive corrosion layer to protect itself from oxides, increasing both its strength and overall longevity.

Fibre optics
4 Able to transmit over great distances, optical fibres enabled the modern age of the internet, broadcasting and even telecommunications to really take off.

Kevlar
5 An artificial fibre developed and produced in a lab, Kevlar is still one of the strongest materials on Earth and is frequently used in body armour by police and soldiers.

DID YOU KNOW? The most powerful man-made magnets have fields more than a million times stronger than Earth's!

CARBON NANOTUBE



Carbon nanotubes can also reduce biofouling of ship hulls by preventing algae and barnacles sticking to them

Absorbs over 99.5% of light

Carbon nanotubes are said to outperform Kevlar and steel in strength. By having a high specific strength, carbon nanotubes can absorb high impacts by spreading out the force. As well as being strong, the fibre is also ductile and malleable. These characteristics render the material useful as a possible replacement for steel, as well as being applied as synthetic muscles and body or vehicle armour.

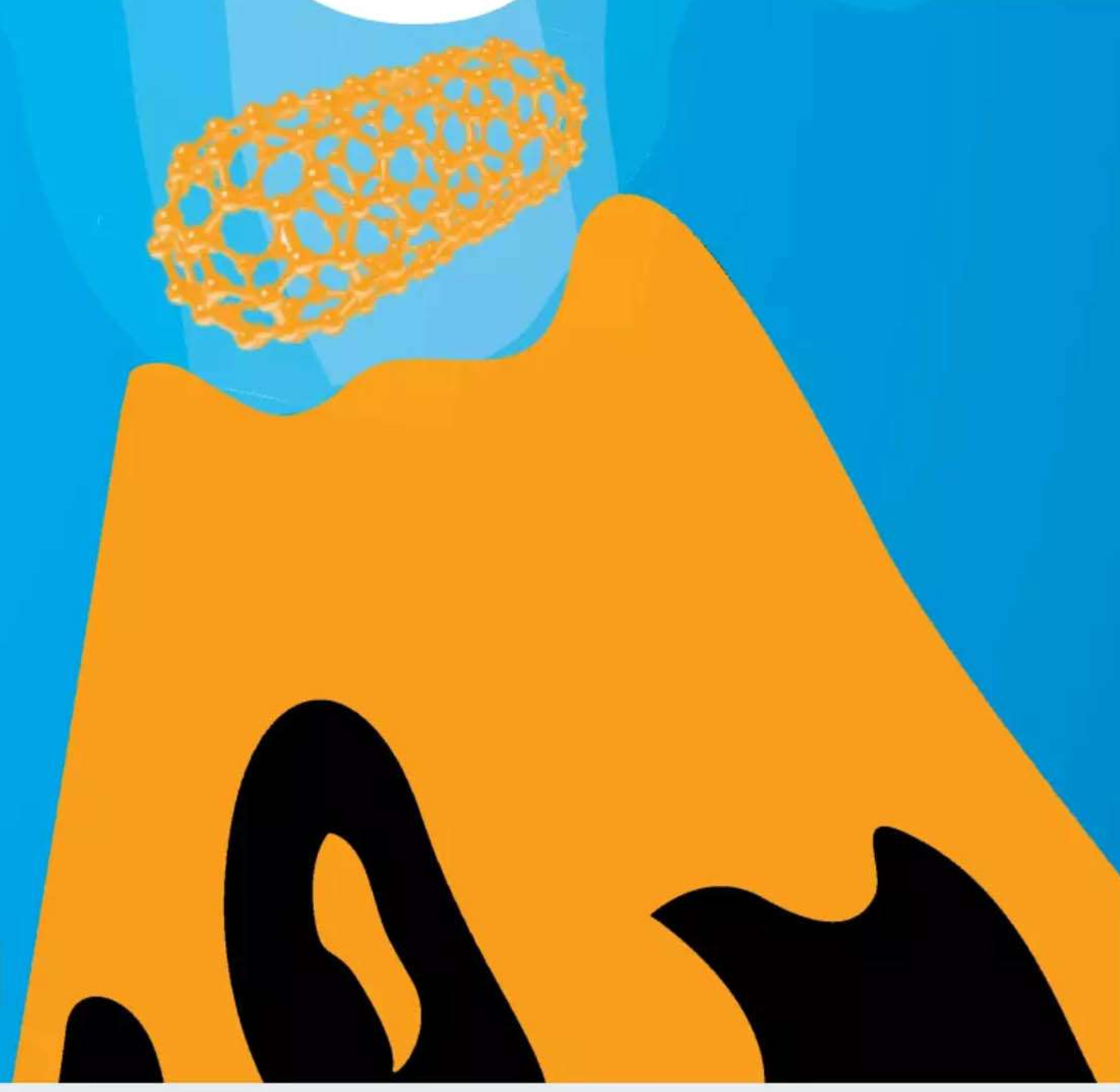
If all that wasn't enough, the computing world has also found a use for this super material with its potential to be a long-term replacement for today's silicon computer chips.

Moreover, certain types of carbon nanotube developed by NASA are said to be the darkest material known to man, due to their ability to absorb over 99.5 per cent of photons. This is particularly useful for stopping stray light interfering with sensitive equipment on probes and spacecraft. This property also offers huge potential for more effective solar panels.

- Absorbing multiple wavelengths of light
- Silicon transistors in electronic devices
- Environmental concerns have stalled its progress so far

800°C

A nanometre of carbon nanotubes is heat resistant enough to withstand lava



"Carbon nanotubes are molecular-scale tubes of graphitic carbon with outstanding properties. They are among the stiffest and strongest fibres known, with a breaking strain around 50 times higher than steel. Carbon nanotubes have an important advantage over graphene, in that they are stiff and strong in compression as well as tension; graphene can't withstand any compression"

Peter Harris, Reading University, and author of *Carbon Nanotube Science*

5 natural inspirations

1 Lotus leaf

When raindrops land on the leaves of the lotus, they cannot settle on the plant. This is down to microscopic bumps over the surface, which increase the contact angle. As the water hits these protrusions, with pockets of air trapped in between, it beads up into spheres and rolls off.

2 Gecko feet

Geckos have the ability to cling to surfaces with adhesive pads called setae on their feet. However, this skill comes undone in wet weather, hence why scientists today are looking to advance on this natural ability by making a waterproof adhesive.

3 Kawazulite

This mineral is a conductor on the outside and an insulator on the inside. It looks set to play a big role in future synthetic insulators.

4 Spider silk

Tough and adaptable, spider silk has been used for everything from fish nets to gun crosshairs. Humans have created similar synthetic products such as Kevlar, however these generate a great deal of pollution.

5 Gold nanoparticles

Also called nanogold, these tiny particles are 500 times smaller than the width of a human hair. They have excellent molecular-recognition properties and can detect the proteins on cancer cells by using specialised antibodies.

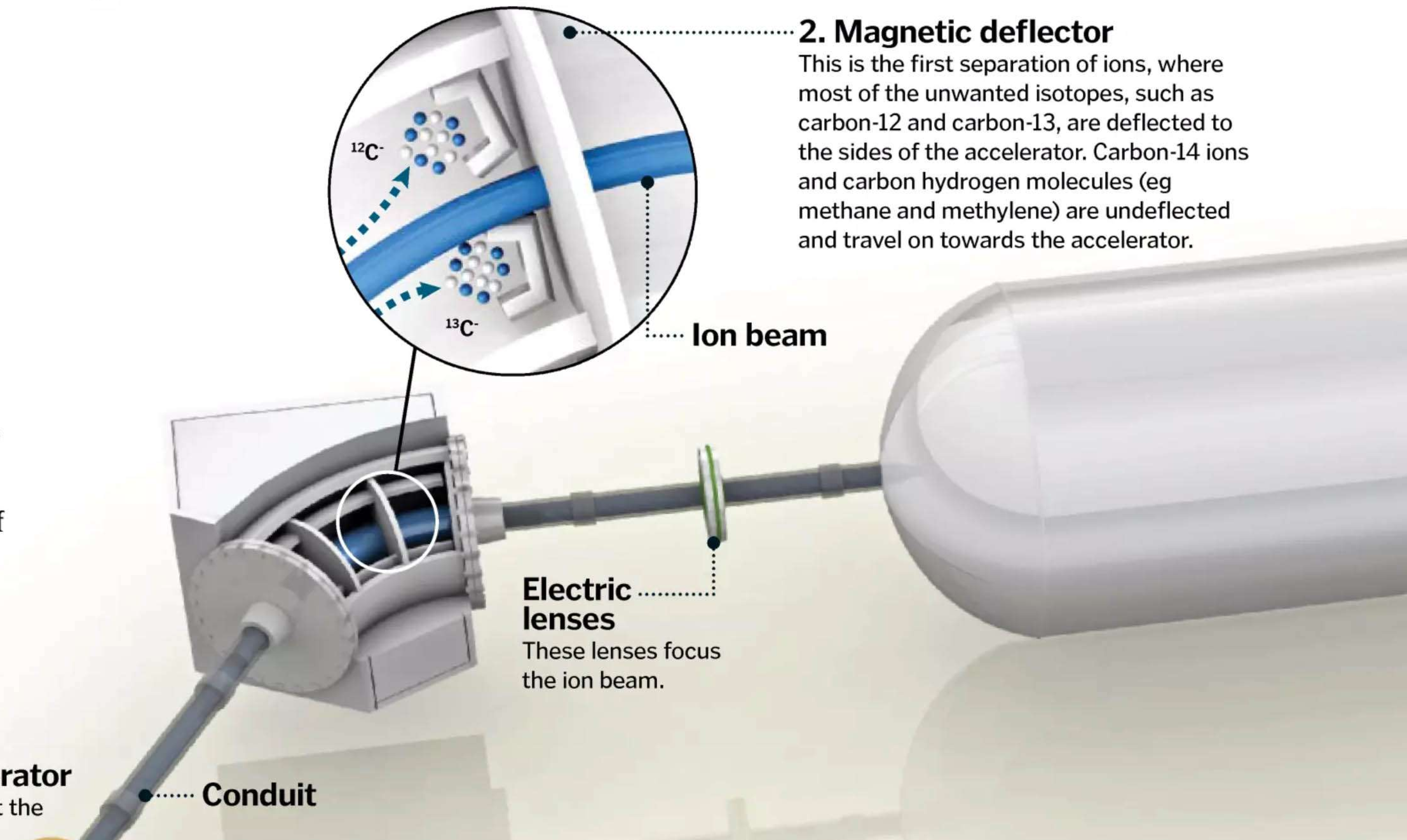
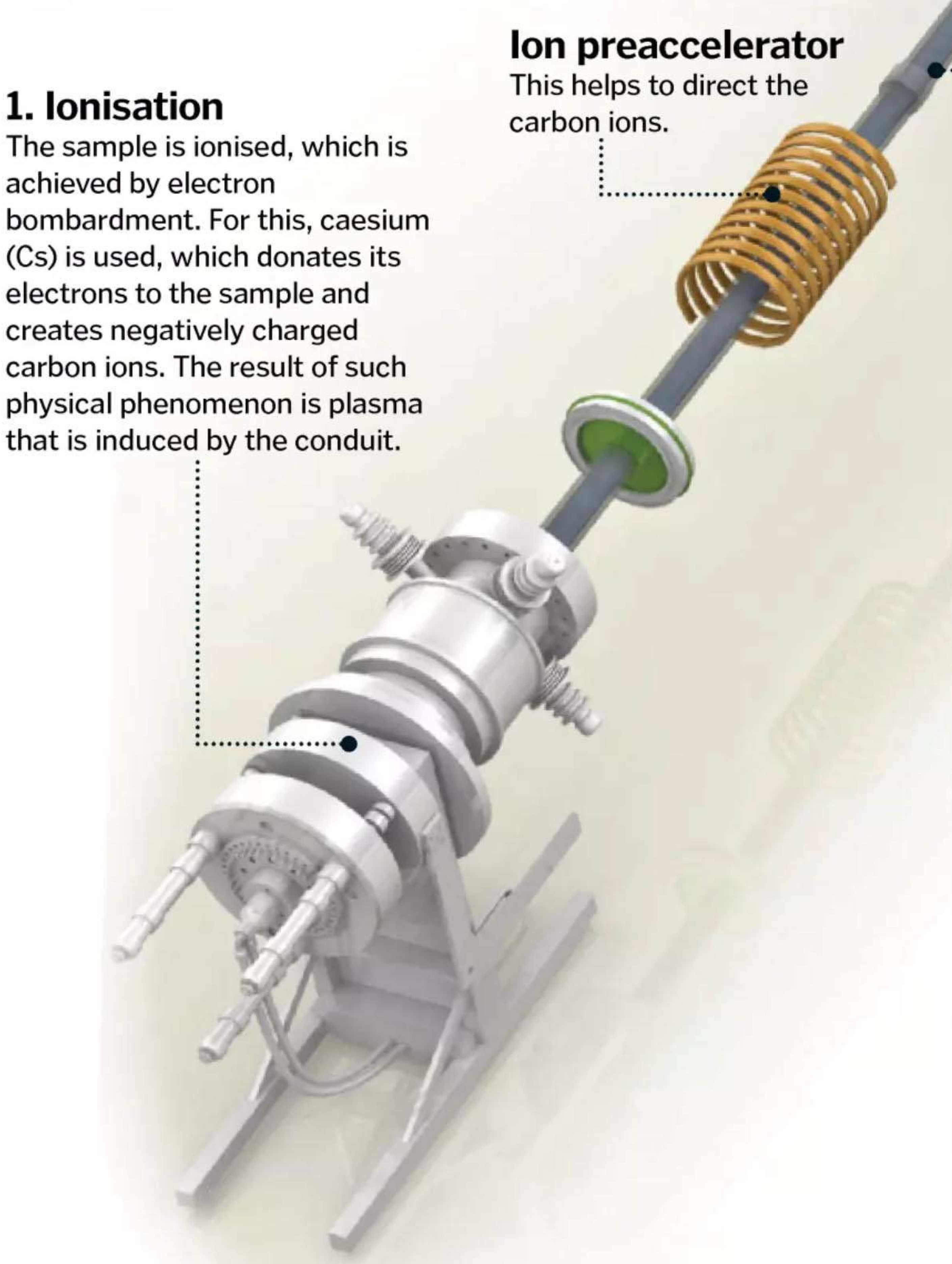
"The radiocarbon dating process is a dependable method of measuring the age of organic remains"

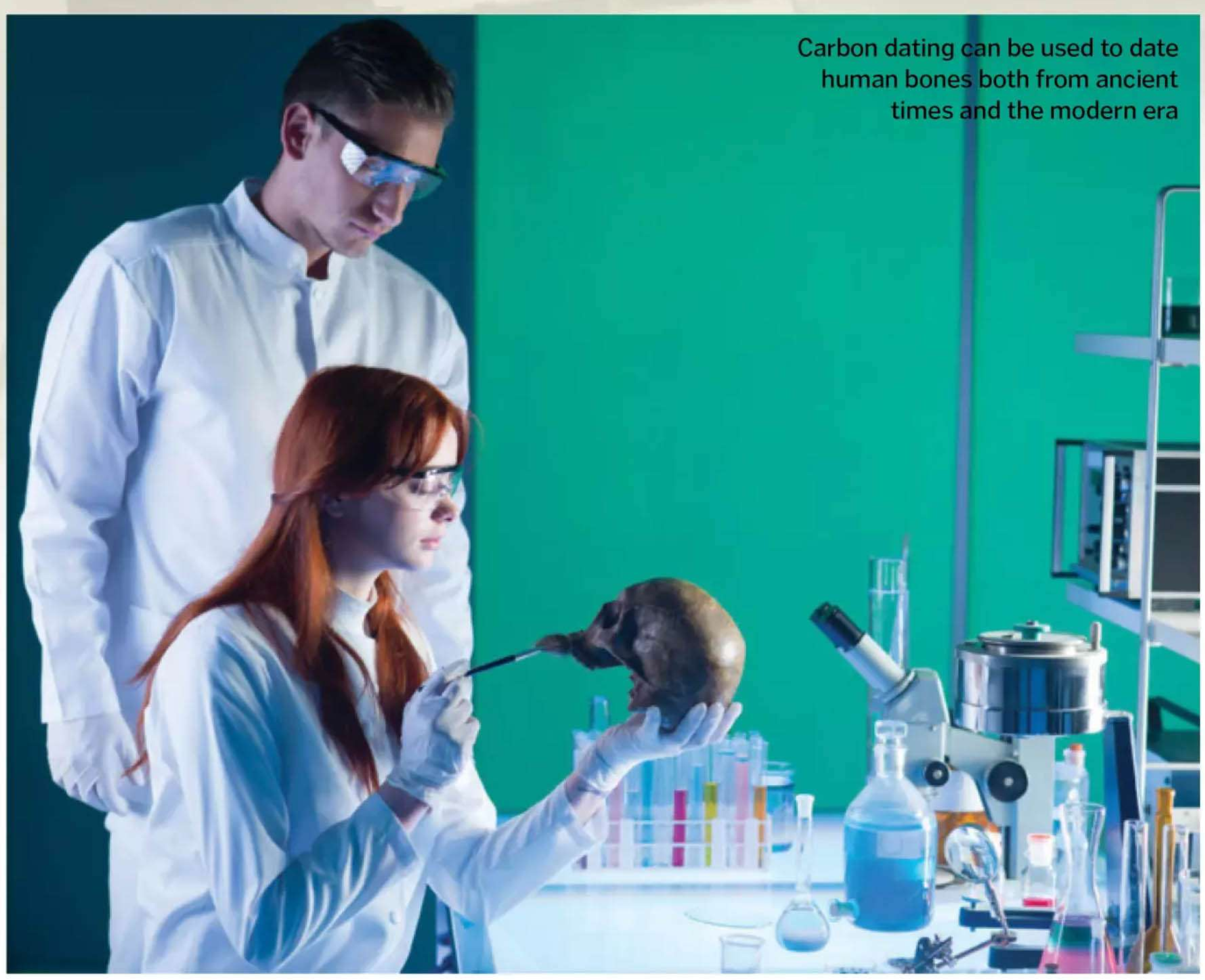
How is carbon dating used to age remains?

Learn how science and technology are working hand in hand to pinpoint the age of ancient organisms, including humans

Carbon dating is an ageing process that works by studying the decay of nitrogen in radiocarbon (carbon-14), with this substance present in every organic being. Carbon-14 is an intrinsic part of the biological carbon cycle on Earth, entering via green plants from the atmosphere and then passing up the food chain via animals. As such, while an organism is alive it will have a consistent level of carbon-14 stored in its cells.

Once an organism dies, however, that level of carbon-14 begins to decrease – something that occurs very slowly as carbon-14 has a half-life of 5,730 years, give or take 40 years. As a result, by measuring the radiocarbon, we can determine when the lifeform died (ie when the level of carbon-14 in its tissue stopped being topped up), though only to around 60,000 years ago.


Carbon dating can be used to date human bones both from ancient times and the modern era

KEY DATES
CARBON DATING

1946
Willard Libby publishes a paper proposing that the carbon in living matter may contain carbon-14.

1947
Libby and collaborators prove his theory correct with their findings published in *Science*.

1949
Libby and scientist James Arnold date pieces of Ancient Egyptian wood dating to 2800 BCE.

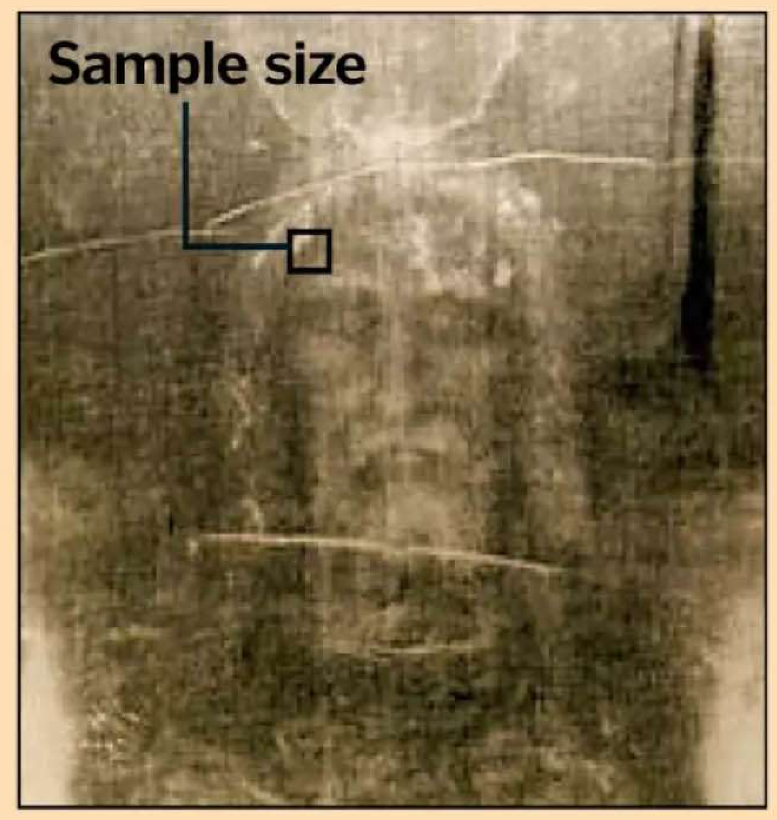
1960
Libby is awarded the Nobel Prize in Chemistry for his development of radiocarbon dating.

1977
An accelerator mass spectrometer is used for the first time to measure carbon-14 in samples smaller than a milligram.

DID YOU KNOW? Carbon has two non-radioactive isotopes (carbon-12/13) and one radioactive isotope (carbon-14)

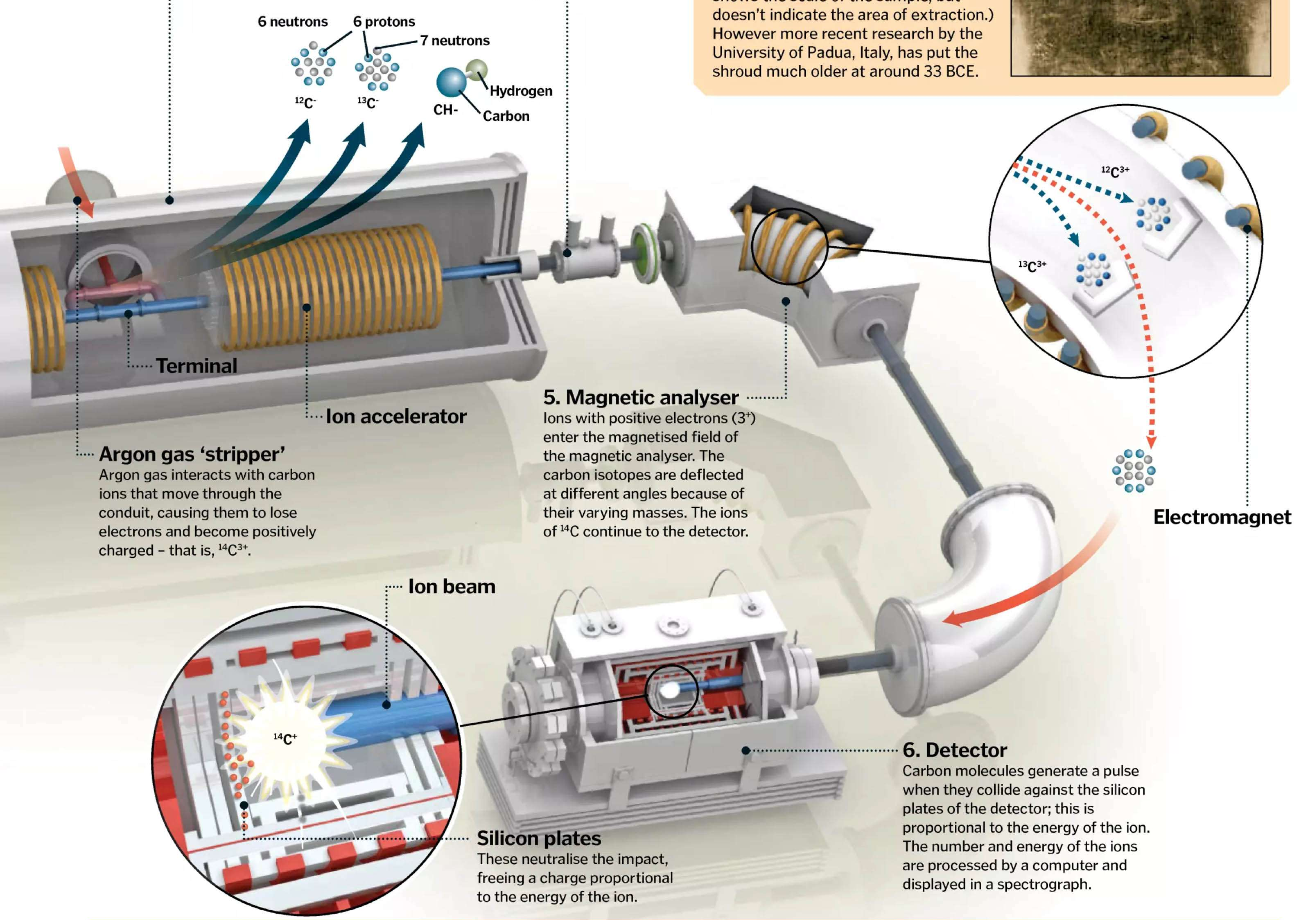
The Turin Shroud

Three universities were chosen to date the ancient linen Turin Shroud in 1988, believed by some to have covered Jesus after he was crucified, but carbon dating concluded it was a medieval forgery. The sample consisted of a seven-centimetre (2.8-inch) cut, divided into three parts. (This image shows the scale of the sample, but doesn't indicate the area of extraction.) However more recent research by the University of Padua, Italy, has put the shroud much older at around 33 BCE.



3. Accelerator
This generates a high voltage, forcing the negatively charged carbon ions to accelerate towards the positive terminal, where electrons are removed by a gas 'stripper'. These positive ions are then repelled by the positive terminal, accelerating towards the electrostatic deflector.

4. Electrostatic deflector
This device creates an electrostatic field that deflects ions with a lower positive charge. Carbon atoms with higher positive charge, meanwhile, continue through the conduit.



Argon gas 'stripper'
Argon gas interacts with carbon ions that move through the conduit, causing them to lose electrons and become positively charged – that is, $^{14}C^{3+}$.

5. Magnetic analyser
Ions with positive electrons (3^+) enter the magnetised field of the magnetic analyser. The carbon isotopes are deflected at different angles because of their varying masses. The ions of ^{14}C continue to the detector.

Silicon plates
These neutralise the impact, freeing a charge proportional to the energy of the ion.

6. Detector
Carbon molecules generate a pulse when they collide against the silicon plates of the detector; this is proportional to the energy of the ion. The number and energy of the ions are processed by a computer and displayed in a spectrograph.

Five alternative methods used to date artefacts

1. Dendrochronology
The technical name for dating tree rings. Every tree produces a ring per year, with the thickness varying according to climatic conditions. This method is very accurate, but is only useful for ageing up to 10,000 years back.

2. Rehydroxylation
Commonly used to date ceramic wares, this technique enables us to measure the amount of water that the clay elements have reabsorbed since they were fired to reveal fairly accurately when they were made.

3. Potassium-argon
Like carbon-14, it is based on radioactive decay, but in the potassium-40 isotope. It can date rocks that are billions of years old, but due to the long half-life of potassium-40, it's not generally used for samples under 100,000 years old.

4. Uranium-238
This form of radioactive dating depends on the decay of uranium-238. Materials that are billions of years old can be dated with this technique, offering the chance for speculation about the very origins of Earth.

5. Thermoluminescence
This method measures the radiation emitted by the crystalline structure of inorganic matter, like pottery, in a time range similar to that of carbon-14. One of the main drawbacks of thermoluminescence is its high error margin.

"Local anaesthetics provide a short-term blockade of nerve transmission"

How anaesthesia works

By interfering with nerve transmission these special drugs stop pain signals from reaching the brain during operations

Anaesthetics are a form of drug widely used to prevent pain associated with surgery. They fall into two main categories: local and general. Local anaesthetics can be either applied directly to the skin (as a cream, for example) or injected. They are used to numb small areas without affecting consciousness, so the patient will remain awake throughout a procedure.

Local anaesthetics provide a short-term blockade of nerve transmission, preventing sensory neurons from sending pain signals to the brain. Information is transmitted along nerves by the movement of sodium ions down a carefully maintained electrochemical gradient. Local anaesthetics cut off sodium channels, preventing the ions from travelling through the membrane and stopping electrical signals travelling along the nerve.

Local anaesthesia isn't specific to pain nerves, so it will also stop information passing from the brain to the muscles, causing temporary paralysis.

General anaesthetics, meanwhile, are inhaled and injected medications that act on the central nervous system (brain and spinal cord) to induce a temporary coma, causing unconsciousness, muscle relaxation, pain relief and amnesia.

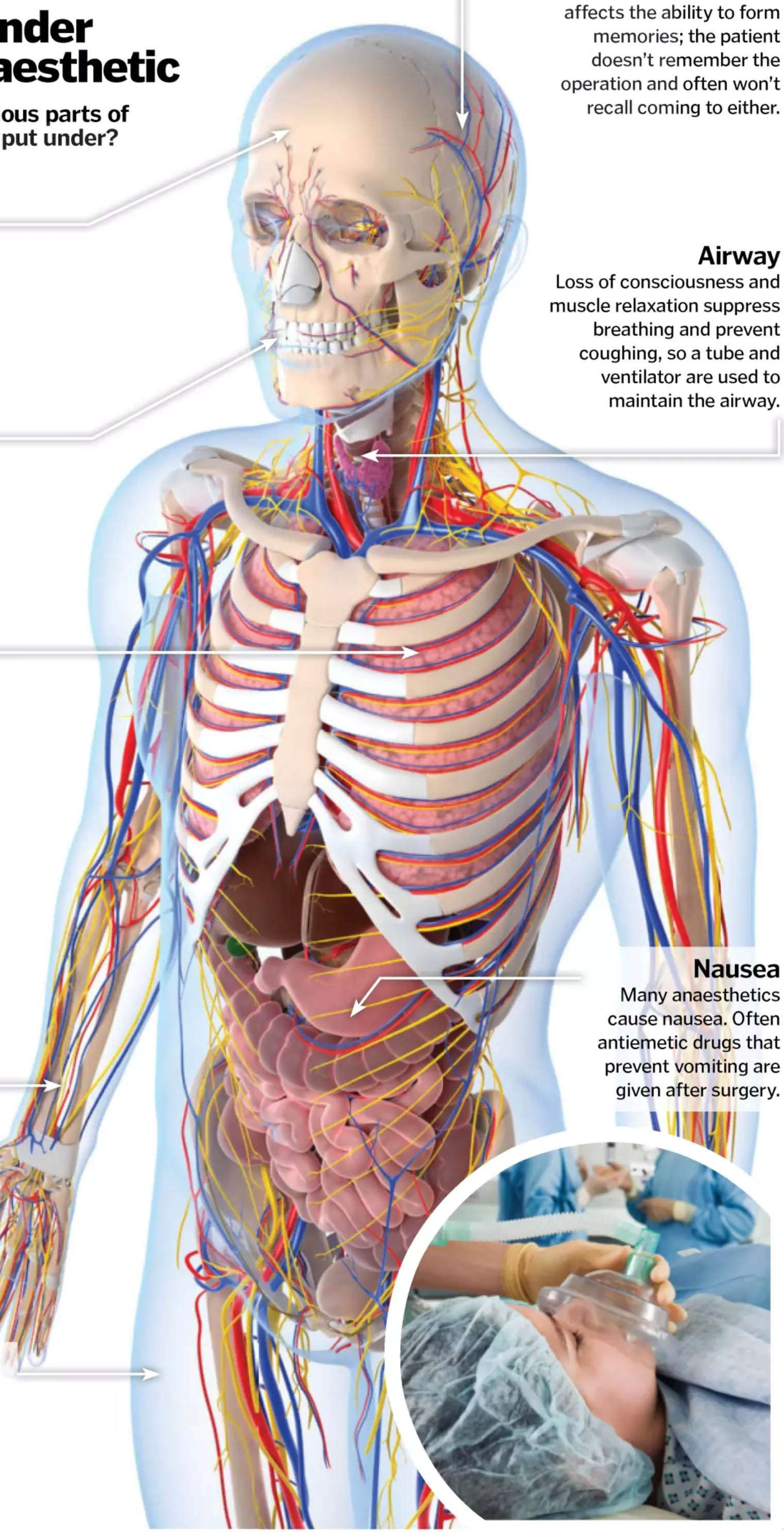
It's not known for sure how general anaesthetics 'shut down' the brain, but there are several proposed mechanisms. Many general anaesthetics dissolve in fats and are thought to interfere with the lipid membrane that surrounds nerve cells in the brain. They also disrupt neurotransmitter receptors, altering transmission of the chemical signals that let nerve cells communicate with one another.

Comfortably numb

If large areas need to be anaesthetised while the patient is still awake, local anaesthetics can be injected around bundles of nerves. By preventing transmission through a section of a large nerve, the signals from all of the smaller nerves that feed into it can't reach the brain. For example, injecting anaesthetic around the maxillary nerve will not only generate numbness in the roof of the mouth and all of the teeth on that side, but will stop nerve transmission from the nose and sinuses too. Local anaesthetics can also be injected into the epidural space in the spinal canal. This prevents nerve transmission through the spinal roots, blocking the transmission of information to the brain. The epidural procedure is often used to mollify pain during childbirth.

The body under general anaesthetic

What happens to various parts of the body when we're put under?



Memory
General anaesthetic affects the ability to form memories; the patient doesn't remember the operation and often won't recall coming to either.

Brain activity
Electroencephalograms (EEGs) show that the electrical activity in the brain drops to a state deeper than sleep, mimicking a coma.

Airway
Loss of consciousness and muscle relaxation suppress breathing and prevent coughing, so a tube and ventilator are used to maintain the airway.

Nil by mouth
General anaesthetics suppress the gag reflex and can cause vomiting, so to prevent choking patients must not eat before an operation.

Heart rate
The circulatory system is slowed by anaesthetic, so heart rate, blood pressure and blood oxygen are all continuously monitored.

Pain neurons
Unlike with local anaesthetic, pain neurons still fire under general anaesthesia, but the brain does not process the signals properly.

Nausea
Many anaesthetics cause nausea. Often antiemetic drugs that prevent vomiting are given after surgery.

Muscle relaxation
A muscle relaxant is often administered with the anaesthetic; this causes paralysis and enables lower doses of anaesthetic to be used.

Why were glow sticks originally invented?

A For parties **B** As a military tool **C** To see in the dark

Answer:
Glowsticks are commonly used at raves and concerts nowadays but they were originally invented to be a military tool. Developed by the US Navy in the 1960s, they were used as emergency lights and target markers.

DID YOU KNOW? *Colds can't be treated by antibiotics because they're caused by viruses, not bacteria*

Antibiotics

How do these drugs cure infections?

Bacteria are single-celled organisms that, if they are able to bypass our immune system, can cause diseases. Different types of antibiotics work in different ways to rid our bodies of unwanted bacteria. Bacterial antibiotics kill bacteria, while bacteriostatic merely stop bacteria from growing.

Antibiotics can damage bacteria in these ways by breaking the cell wall. The cell wall of bacteria protects them from the surrounding environment, but antibiotics can damage this barrier so that when the bacteria try to multiply into two, they will burst.

Other antibiotics, such as penicillin, prevent bacteria from producing important chemicals that they require in order to survive. More still can alter the genetic material in a bacterial cell and stop it from multiplying, an example of which is chloramphenicol, which is used to treat eye infections.

Antibiotics are selective. They will only affect the bacterial cells they have been designed to target, leaving the other cells in the body to their own devices.

Antibiotics are ineffective against viral infections such as the common cold

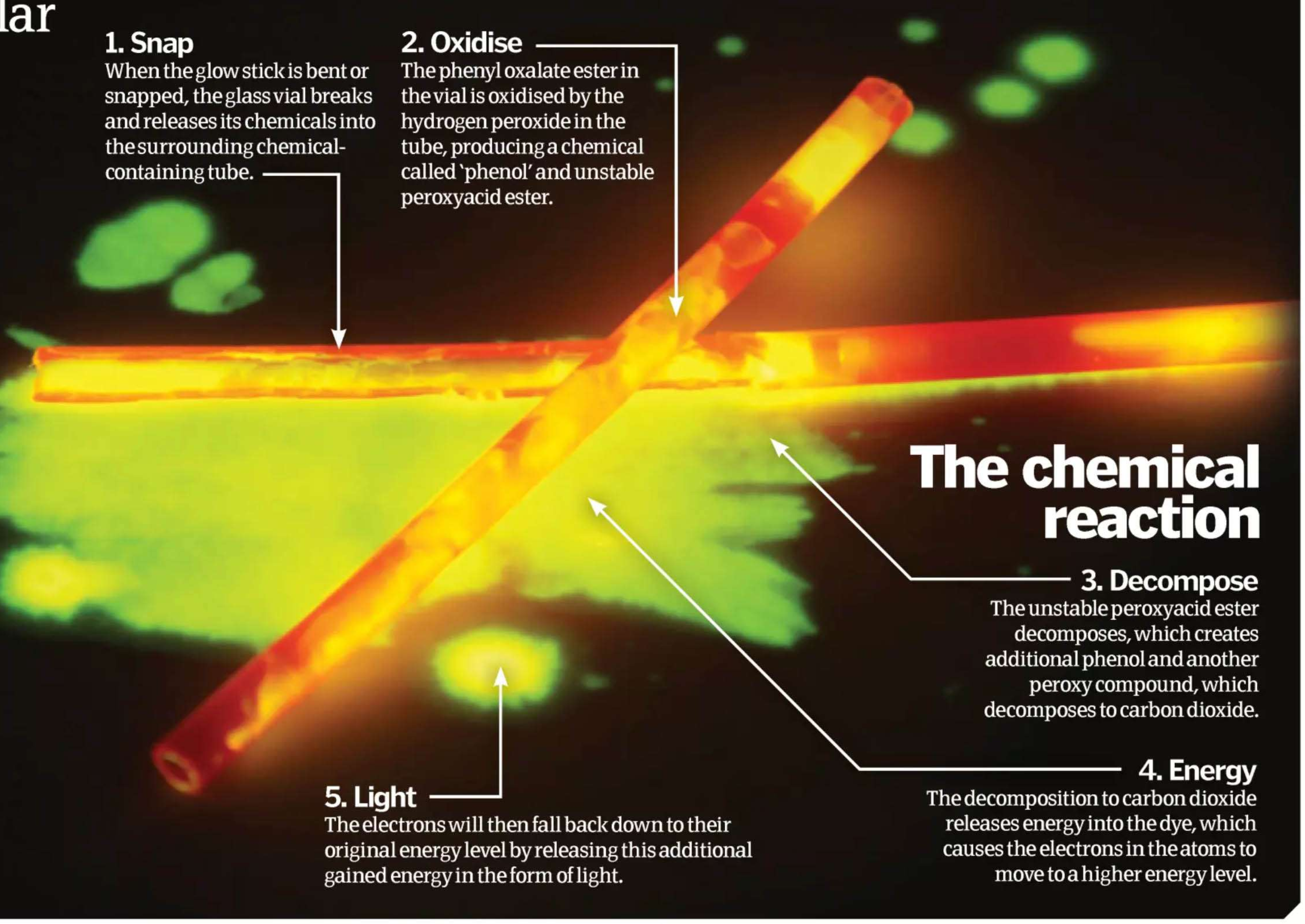
Bacteria learn to resist the effects of antibiotics so the more often you take them the more resistant the bacteria become

Why do glow sticks glow?

What's going on inside these popular light sticks?

Inside a glow stick is a thin glass vial containing chemicals. When you bend the stick you're breaking this vial open, releasing the chemicals into the rest of the glow stick, where other chemicals react with them and release light.

Some chemical reactions produce light, known as 'chemiluminescence'. Usually the vial contains a solution phenyl oxalate ester and a fluorescent dye – which will determine the colour of the glow stick – while the surrounding tube contains a solution of hydrogen peroxide. Mixing these compounds causes the electrons to rise to a higher energy level and return to their normal state, releasing energy as light as they do.



"As noble gases show extremely low reactivity only a few hundred noble gas compounds have been formed"

How do noble gases work?

What makes this select bunch of chemical elements so 'noble'?

There are six naturally occurring noble gases found around our world and beyond. These are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Together they form Group 18 of the periodic table and are characterised by their lack of colour, smell, taste and flammability in their natural state.

Despite being historically referred to as rare and inert, noble gases – which were designated 'noble' due to their apparent reluctance to undergo a chemical reaction – are nothing of the sort. In fact, all of these gases are found in Earth's atmosphere and each is capable of being chemically active and producing compounds.

The majority of the noble gases – ie argon, krypton, neon and xenon – are formed via liquefaction and fractional distillation techniques, however helium is attained by separating it from natural gas and radon by isolating it from the radioactive decay of radium compounds.

As noble gases show extremely low chemical reactivity, while they are not inert, only a few hundred noble gas compounds have been formed to date, with xenon varieties making up the bulk. In theory, though, radon is more reactive than xenon, so should form chemical bonds more readily. However, its high radioactivity and short half-life are the key factors which prevent this.

There are many applications for noble gases (see the boxout below for some notable examples). The most obvious and visible of these are illuminated signs, light bulbs and lamps, with xenon, argon and neon commonly used due to their lack of chemical reactivity. Using these gases helps to preserve filaments in light bulbs and grants distinctive colours when used in gas-discharge lamps – as demonstrated by the main image on this page.

Where are noble gases used?

Arc lamps

A specialised type of gas-discharge lamp, arc lights pass electricity through a bulb full of ionised gas, such as xenon or argon. They're used in IMAX cinemas among other places.

Blimps

Today, most blimps are filled with helium due to its lightness and incombustibility. Hydrogen was used originally but was phased out due to its high flammability.

MRI scanners

One of the most advanced pieces of medical equipment, magnetic resonance imaging scanners use liquid helium to cool the superconducting magnets inside.

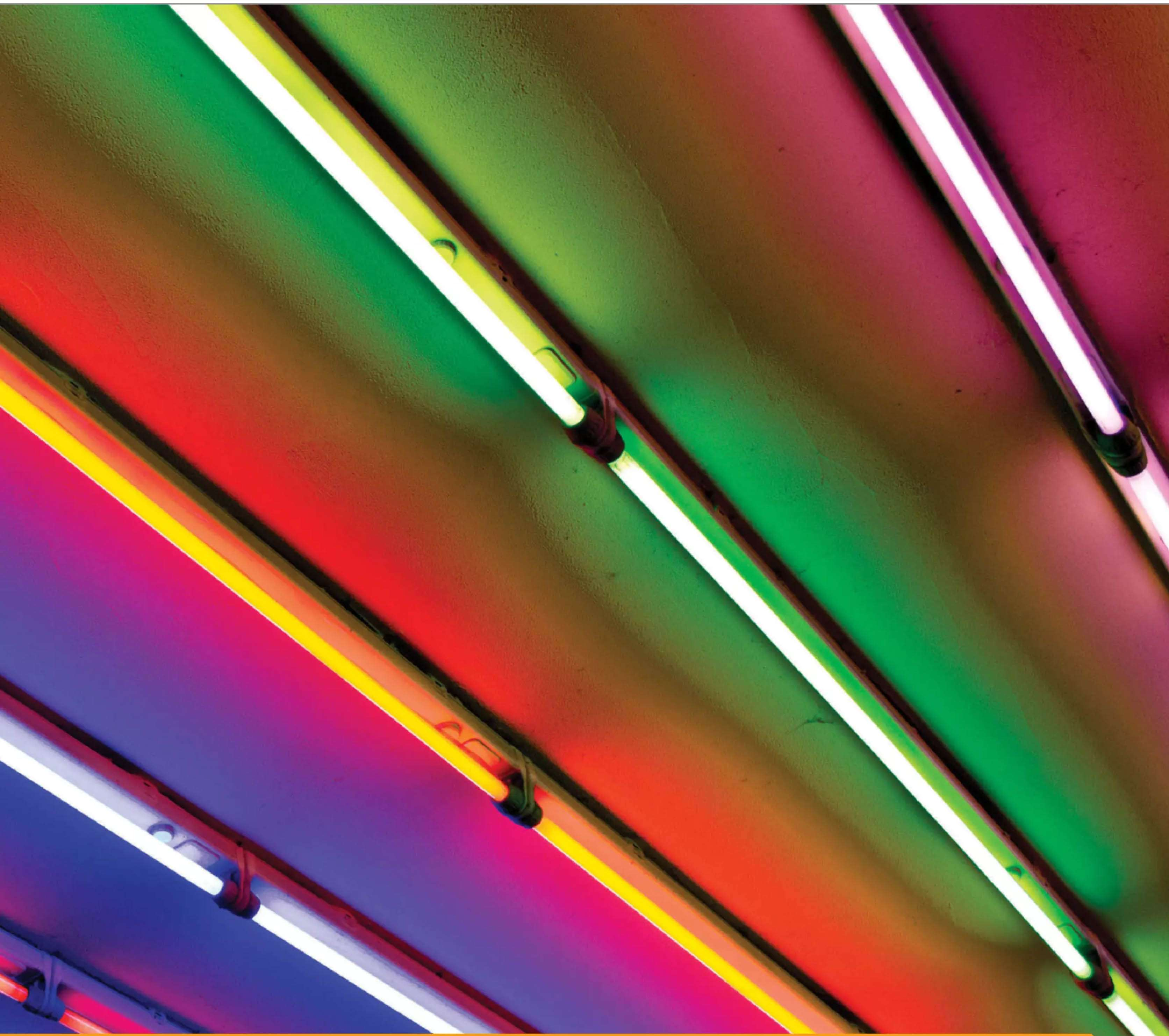
RECORD BREAKERS
BOILING COLD

-268.9°C

LOWEST BOILING POINT

-268.9 degrees Celsius (-452 degrees Fahrenheit) is the chilly boiling point of the noble gas helium. It is the lowest of any element in the entire periodic table.

DID YOU KNOW? *The first noble gas compound was formed from xenon in 1962 by British chemist Neil Bartlett*



Illuminated signs

Many illuminated signs and billboards utilise noble gases due to their ability to generate vibrant colours when ionised – neon lights being a prime example.

Refrigerants

Due to their incredibly low boiling points – for instance, argon boils at -186 degrees Celsius (-302.8 degrees Fahrenheit) – the Group 18 gases are often used in cryogenics.

Radiotherapy

Despite the noble gas radon being highly radioactive and able to cause cancer, it can also be used as part of radiotherapy treatments to control or kill malignant cells.

> "A strong acid has a high concentration of H+ ions"

Acids and bases

Discover the differences between acids and bases, and find out why they act the way they do

It is widely known that lemons taste sour due to their acid content, soil needs the optimum pH level for plants to grow properly and acid rain can wipe out entire ecosystems. But what really makes one thing acidic and the other one basic (alkaline)? Why can they be so corrosive? And why does litmus paper turn different colours when dipped in acid or a base?

Acids and bases can be defined in terms of their concentration of hydrogen ions. Normally an atom of hydrogen consists of one proton and one electron giving it a balanced electrical charge – protons being positively charged and electrons being negatively charged. Take away the electron and you are left with an ion of hydrogen, or a single proton, or 'H+', as it is often written. The thing about ions is they are very reactive, as they no longer have a balanced charge. They are constantly seeking ions of the opposite charge – an atom or molecule with an unequal number of electrons than protons, with which to react.

A strong acid has a high concentration of H+ ions and is defined by its ability to 'donate' hydrogen ions to a solution, whereas a base, also know as an alkali, has a much lower concentration of H+ ions and is defined by its ability to 'accept' hydrogen ions in a solution. Therefore, acids mixed with bases become less acidic and bases mixed with acids become less basic, or less alkaline.

Certain concentrated bases, like some concentrated acids, can attack living tissue and cause severe burns due to the ions reacting with the skin. However, the process of bases reacting with the skin, and other materials, is different to that of acids. That's why we call some concentrated acids 'corrosive', whereas reactive concentrated bases are 'caustic'.


Acids and bases have many uses, but stronger ones can be harmful

The power of hydrogen

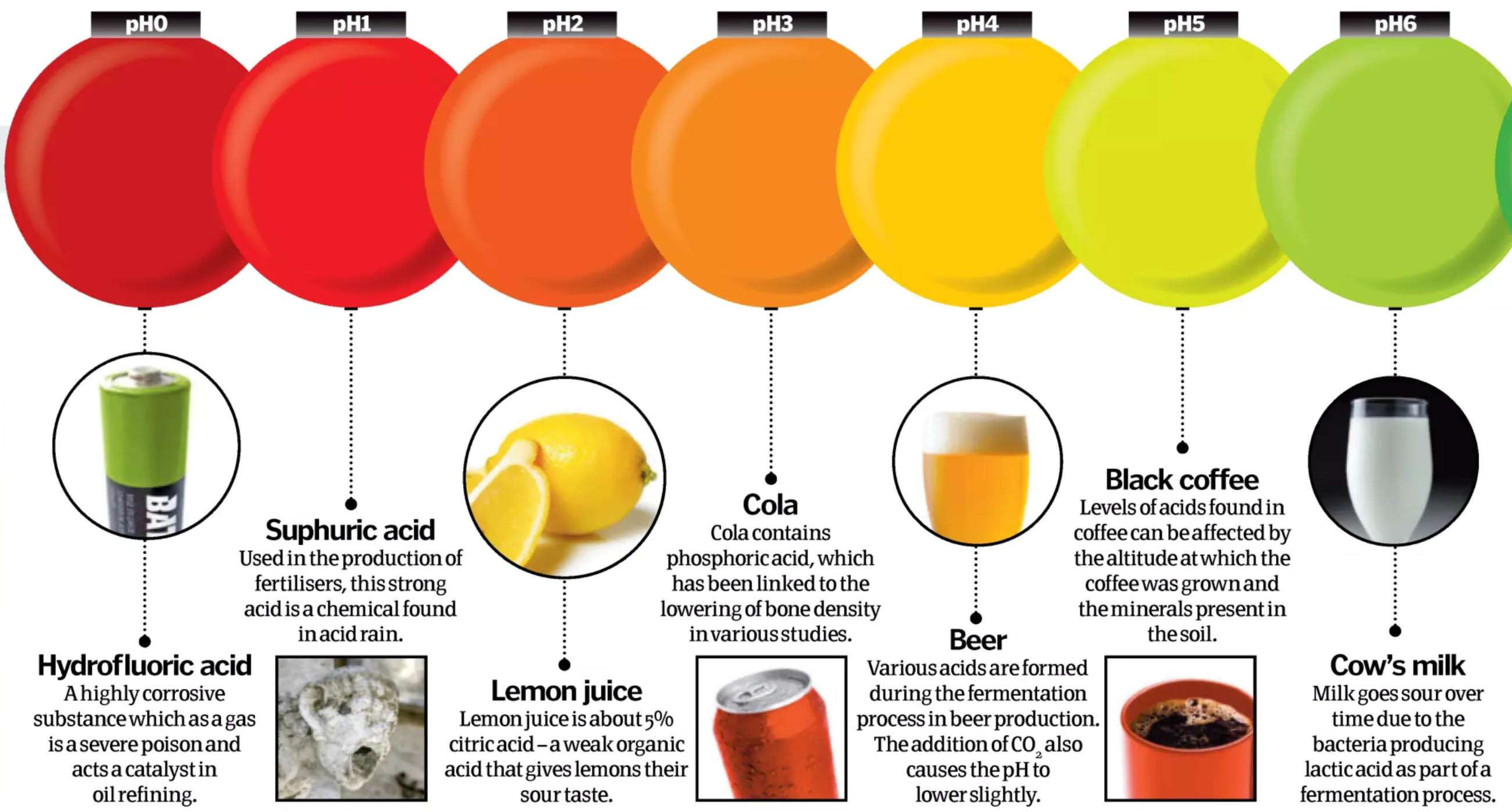
The letters pH stand for 'power of hydrogen', as the scale refers to the concentration of hydrogen (H+) ions in the solution. It measures the acidity or basicity of a solution, with pH values ranging from 0-14, 0 being really acidic and 14 being really basic. A substance in the middle of the scale with a pH of 7 is classed as neutral, as it contains equal numbers of oppositely charged ions.

Acid

A compound which 'donates' hydrogen ions when placed in an aqueous solution. The higher the concentration of hydrogen ions released, the stronger the acid.


Some natural boiling acid springs have a pH of about 1, similar to battery acid

© Allison Choppick



HEAD 2 HEAD
CORROSIVE SUBSTANCES

1. CORROSIVE

Sulphuric acid
Sulphuric acid releases heat upon contact with water, used in the steel industry to remove rust and oxidation. XXXXXX

2. MORE CORROSIVE

Hydrofluoric acid
Hydrofluoric acid is highly corrosive, and it has the ability to dissolve most oxides including glass.

3. MOST CORROSIVE

Sodium hydroxide
This is a highly caustic base that in high concentrations can be severely damaging to living tissue.

DID YOU KNOW? *Carborane superacids are a million times stronger than sulphuric acid, yet can be entirely non-corrosive*

Neutralisation

A neutralisation reaction is the combination of an acid and base that results in a salt and, usually, water. In strong bases and acids, neutralisation is the result of the exchange of hydrogen and hydroxide ions, H+ and H- respectively, which produces water. With weak acids and bases, neutralisation is simply the transfer of protons from an acid to a base. The production of water, with a neutral pH of 7, indicates the neutralisation of the acid and base, while the resultant salt will often have a pH that is also neutral.

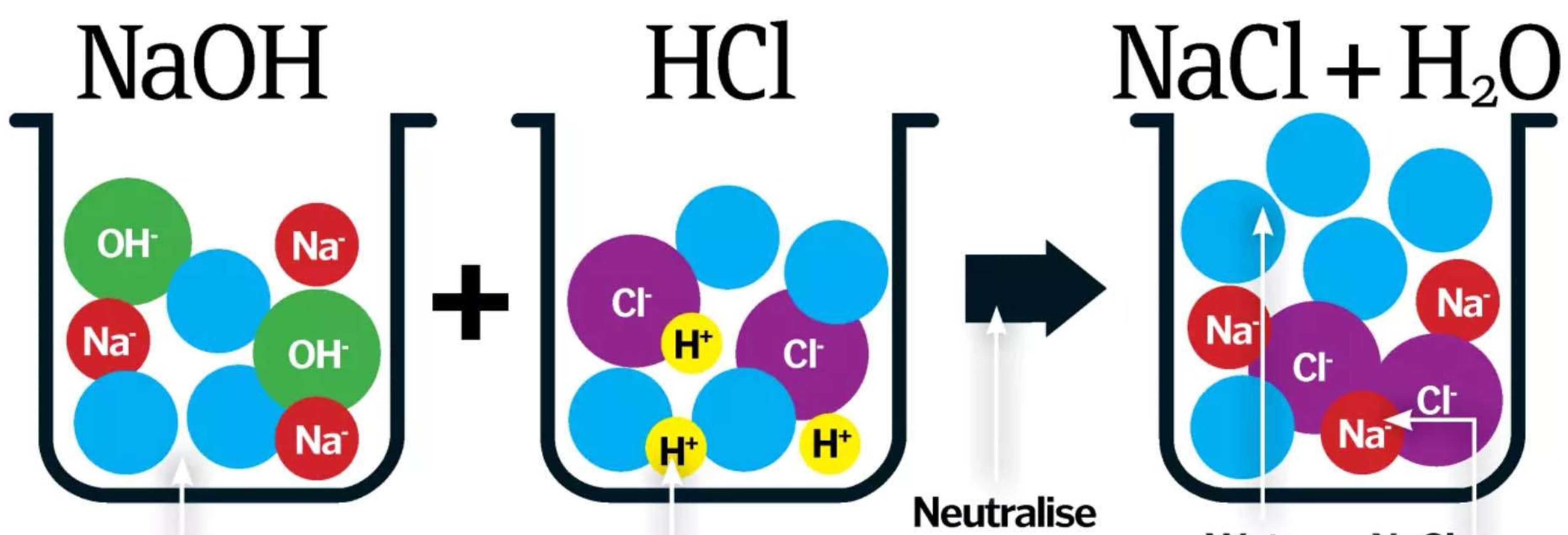
Neutralisation has a variety of practical uses. For example, as most plants grow best at neutral pH7, acidic or alkaline soil can be treated with chemicals to change its pH. In the case of acidic soil this is often calcium carbonate (chalk) or calcium oxide (quicklime). Another example is the human stomach, which contains hydrochloric acid. However, too much can lead to indigestion, so the acid can be neutralised with a base such as an indigestion tablet.

The litmus test

We can test the acidity or alkalinity of a substance using litmus paper. Litmus paper is that which has been treated with a mixture of 10-15 natural dyes obtained from lichens. The dyes work as indicators, whereby upon exposure to acids (a pH less than 7) the paper turns red and upon exposure to bases (a pH more than 7) the paper turns blue. When the pH is neutral (pH equal to 7), the dyes cause the paper to turn purple.

Red cabbage juice can also be used to distinguish between acids and bases, as it contains a natural pH indicator called 'flavin'. Upon exposure to acid, flavin turns a red colour, neutral solutions appear a purple colour and basic solutions result in a greenish-yellow colour.

How do an acid and base react to produce salt, water and heat?



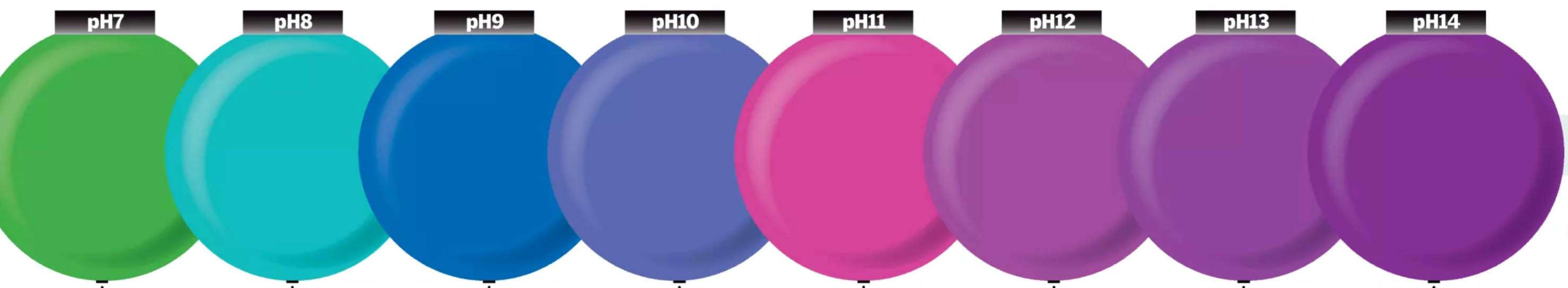
Sodium hydroxide
This strong alkali (a base soluble in water) has a pH of 13 or 14.

Hydrochloric acid
With a pH of 1 or 2, the H+ ions of this strong acid are removed by the alkali.

Neutralise
By removing the H+ ions, the alkali neutralises the acid and turns the ions into water.

Water
Neutral water of pH7 is produced.

NaCl
Neutral sodium chloride, or table salt, is also produced.



Base

A compound which 'accepts' hydrogen ions in an aqueous solution. Contains ions of the opposite charge. For example, hydroxide (OH-) which is naturally found in water and is negatively charged.

Distilled water
Pure water is neutral as it contains the same amount of positive ions as negative ions, though most water isn't pure in this sense.

Baking soda
A slightly salty substance used as a base in foods to regulate the pH if something is too acidic.

Toothpaste
Acidic toothpaste can put enamel at risk of decay, so a weak base such as sodium hydroxide is added in order to regulate the pH.

Milk of magnesia
A weak base of magnesium hydroxide in water, used to ease stomach aches caused by too much acid.

Ammonia solution
When placed in water, ammonia removes protons from a small fraction of the water to form ammonium and hydroxide. It is used in many cleaning products for its basic properties.

Bleach
Can contain sodium hypochlorite at different strengths, making it a strong caustic base.

Caustic oven cleaner
Heavy-duty oven cleaners can be really caustic and corrosive, helping to break down fat and grease.

Caustic soda
Chemically known as sodium hydroxide, in its purest form it is a white solid and can cause severe burns due to its high alkalinity.

The science behind food

Take a look at the chemistry that goes on in the kitchen when we cook our food

Some of the most interesting kitchen chemistry can be observed when baking. Taking four basic ingredients – flour, fat, sugar and eggs – and subtly altering their cooking chemistry can transform them into airy cakes, chewy cookies or flaky pastries.

Leavening, or raising, agents introduce bubbles of air. As the air bubbles are heated, the gas that they contain expands, causing cakes, breads and soufflés to rise. These air bubbles can be made in one of two ways. Chemical raising agents, like baking powder and bicarbonate of soda, react with water to form carbon dioxide gas. This reaction occurs very rapidly and the quantity of raising agent must be carefully adjusted – too much and the bubbles will become large and burst, too little and the density of the cake mixture will prevent any bubble formation at all.

For a slower rise with added flavour, baker's yeast (Saccharomyces cerevisiae) is often used. Yeast is a single-celled organism of the fungi family. At first, the yeast respires aerobically – using oxygen – creating bubbles of carbon dioxide. When the oxygen runs out, the yeast begins to make ethanol by fermentation, much like in brewing beer, but any alcohol formed in the bread dough evaporates in the oven.

Making bubbles is one thing, but getting them to remain intact requires more clever chemistry. Bread is most often made from wheat flour, which contains starch granules surrounded by two important proteins: glutenin and gliadin. When mixed with water and kneaded, the glutenin cross-links to form networks with gliadin, making a new stretchy protein: gluten. Gluten is a 'super-protein', or protein complex, which behaves much like elastic, forming stretchy bridges that hold the starch molecules together. The key to light, fluffy bread lies in creating lots of tiny elastic bubbles; the more the dough is kneaded and stretched, the stronger the gluten network becomes. Eggs act in a similar way to the gluten in flour, providing a protein-binding agent that supports air bubbles and holds cakes together.

Unlike bread, pastries need to be 'short' and crumbly, so bakers try to minimise gluten production, which would lead to a rubbery texture. This is done by first rubbing butter into the flour, coating the starch molecules with a layer of fat, which helps prevent glutenin and gliadin from coming into contact with water.

The texture of baked goods can also be altered using sugar. When sugar is beaten with butter, the sharp edges of the sugar crystals allow tiny air bubbles to form – turning the mixture a pale, creamy yellow colour. These bubbles expand in the same way as the ones created by raising agents, contributing to the light texture of cakes. For the denser consistency of cookies, melted fats and oils are often used because the tendency for bubbles to form next to the sugar crystals is reduced.

Sugar also draws in moisture from the air, which can have a significant effect on the water content of baked goods. Brown sugar attracts more water than white, and finely ground sugars attract more water than the granulated variety. Experimenting with the type of sugar used in a recipe will alter the final moisture content, and therefore the texture.

Chemistry isn't just limited to baking though. Chemical reactions define the taste of meat – which is around 70 per cent water, with the

RECORD BREAKERS
KING OF PUDDINGS

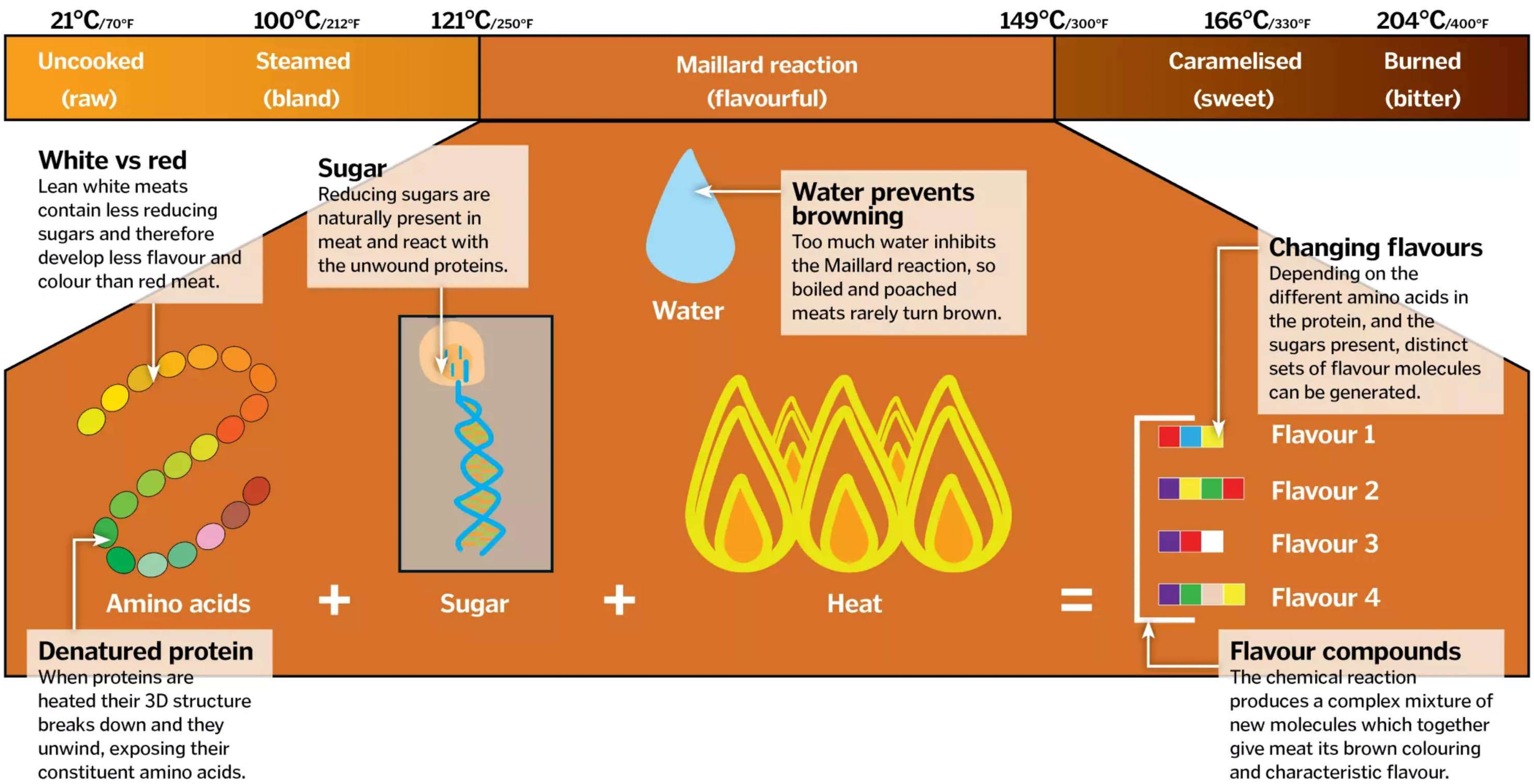
2.1x1.5M

BREAD-'N'-BUTTER BEHEMOTH
Seven chefs, 1,000 slices of bread, 70 apples and 56 eggs were needed to make this mammoth pud 2.1 x 1.5 metres (6.8 x 4.9 feet) in size. It took over 49 hours to prepare.

DID YOU KNOW? *The word 'gluten' – the sticky protein that holds breads/cakes together – comes from the Latin for glue*

Why cooked meat tastes better than raw

The brown colour of seared meat, toasted bread and roasted coffee beans is down to a chemical process called the Maillard reaction. When foods are heated, amino acids (the building blocks of protein) react with sugars to create hundreds of flavour compounds. Depending on the types and quantities of the various amino acids in the food, different combinations of flavours will be produced, as this diagram shows…



remainder being mostly protein and fat. Depending on the cut, meat contains a variable amount of collagen – a fibrous protein in the skin, tendons and connective tissue. The higher the collagen content, the tougher the meat is.

More expensive cuts and meat from younger animals contain little collagen and can be cooked rapidly. The muscle protein myosin denatures (breaks downs) at low temperatures – ie 50 degrees Celsius (120 degrees Fahrenheit) – and begins to form cross-links, lending some support to the structure of meat. At this stage, water molecules between the proteins start to leak out, but the meat remains juicy and tender. At 60 degrees Celsius (140 degrees Fahrenheit) the red pigment in muscle – myoglobin – denatures to form a hemichrome that gives cooked red meat its brown-grey colour.

Further heating causes the collagen to shrink and contract, forcing water out and turning the meat from juicy and tender to chewy and dry. If the temperature is raised still further – to, say, 70 degrees Celsius (160 degrees Fahrenheit) – the meat continues to toughen, but the collagen itself dissolves to form gelatine. Although the ▶

Cracking the makeup of eggs

The protein content of eggs makes them an extremely versatile chemical tool in the kitchen. Egg white contains a number of globular proteins that normally exist as curled-up, ball-like structures suspended in water. When eggs are cooked, however, the proteins uncurl and then come together to form web-like networks of interconnected protein strands. Water becomes trapped in the web, forming the soft texture of cooked egg white. The longer the proteins are heated, the more links are made in the web, forming an ever-tighter texture, which eventually becomes thick and rubbery.

Whisking egg whites before they are cooked introduces many tiny bubbles. The amino acids on the outside of egg white proteins are hydrophilic (water-loving), while those on the inside are hydrophobic (water-hating).

When the proteins press up against an air bubble, the water-loving amino acids try to move away from the air – uncurling the structure of the protein so that they can 'hide' in the thin film of water that surrounds the bubbles. When heated in this uncurled state, the proteins form links to one another, stabilising the bubbles and helping to support the aerated texture of cakes, meringues, soufflés and many other foods.

fibres of meat are more brittle, the gelatine acts as a lubricant, giving slow-cooked meat its soft, 'melt-in-the-mouth' texture.

Heat is not the only way to break down collagen, though, and meat can be physically or chemically tenderised. Marinades use common culinary chemicals to interfere with the bonds between collagen strands – these range from acids like lemon juice to enzymes like bromelain (found in pineapple).

Another great example of kitchen chemistry is the emulsion process. Oil and water don't mix, but to make sauces like mayonnaise and béchamel a cook needs a way to bring them together. When oil and water are combined, the oil floats on top, forming an interface with the water that has high surface tension. In order to break this tension, mechanical shearing can be used – by shaking the container the oil breaks down into smaller and smaller bubbles, which disperse into the water. However, this is only a temporary emulsion (like salad dressing), and after a while the oil and water will separate.

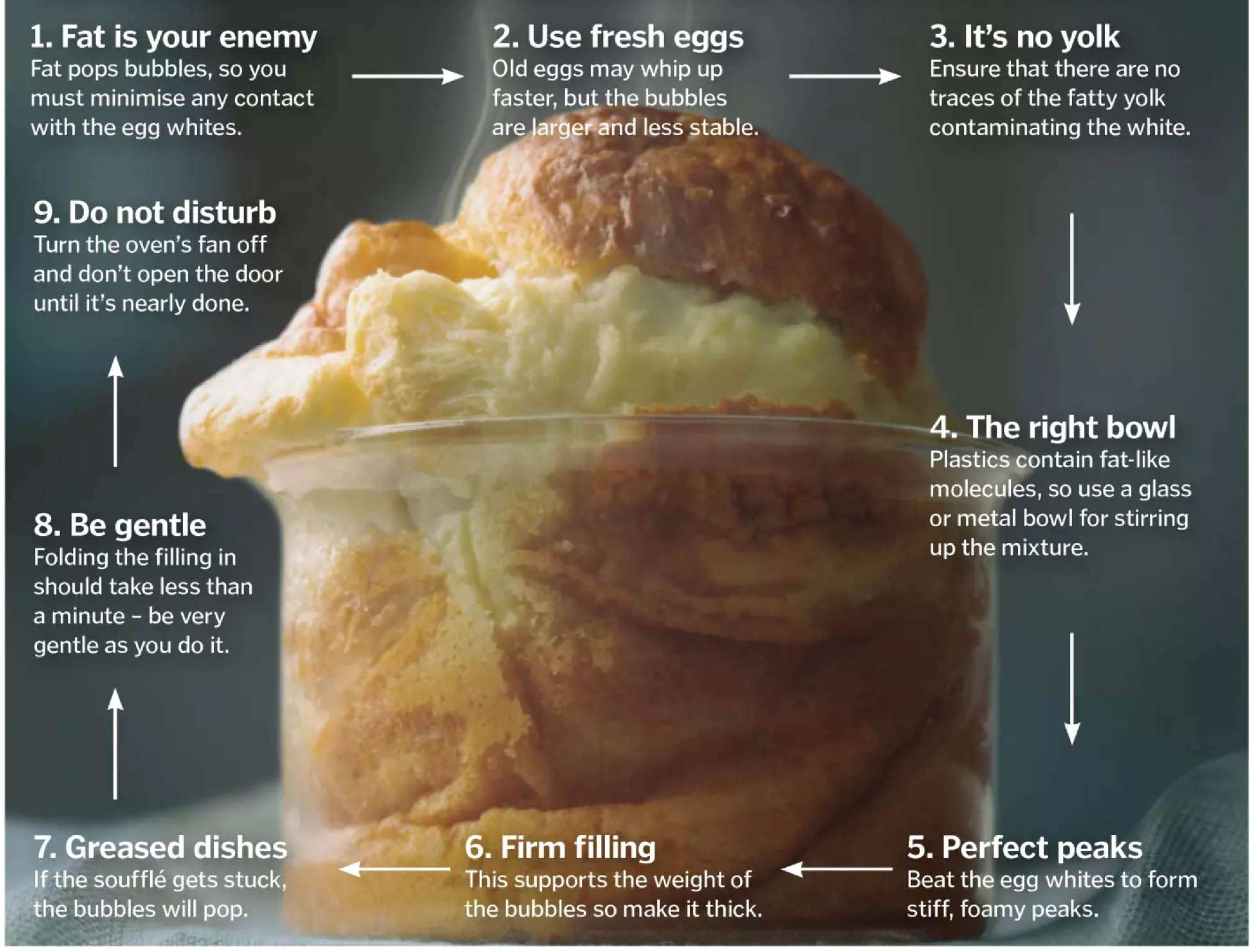
Mayonnaise contains watery egg yolks and fatty butter, which must mix to form a smooth, white paste in a permanent emulsion. Egg yolks contain an emulsifier called lecithin, which dissolves in both fat and water, essentially forming bridges between the yolk and the butter and holding the mayonnaise emulsion in a stable structure. Flour can be used in a similar way in white sauces like béchamel; the fine powder helps to bind the butter to the liquid.

The flavour of food is determined by its combination of volatile components that get into the air and interact with sensory neurons in the nose. Each food may have hundreds of these molecules, but scientists studying flavour combinations have seen that if just one of them matches, foods are likely to go together. The technique is being used to predict many new, unlikely food partners (see 'Strange flavours').

Molecular gastronomy takes the science of cooking to the next level. Looking at food from a purely physical and chemical perspective, a host of chefs and scientists are coming together to identify new flavour combinations and cooking techniques based on science. Using liquid nitrogen, syringes, centrifuges and ultrasound machines, we are starting to reinvent the way we cook. As the founding father of this scientific discipline, Nicholas Kurti, said: "It's a sad reflection on civilisation that while we can and do measure the temperature in the atmosphere of Venus we do not know what goes on inside our soufflés."

The science behind soufflés

Approach soufflé making like a lab experiment and you'll get great results every time



Strange flavour combinations

Some seemingly odd food pairings are surprisingly good, others are just plain disgusting – but why?

Chocolate and salt

Salt actually helps the cells on your tongue to sense the presence of sugar, so it makes chocolate taste even sweeter.

 +  = YUM

Peanut butter and apple

Peanut butter makes up for what an apple lacks in salt and fat, while the apple cuts through the spread's richness and stickiness.

 +  = YUM

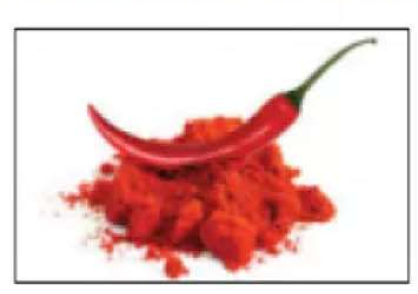
Citrus fruit and milk

The acid found in citrus fruit causes milk to separate and curdle – essentially the first step in making cheese. Not appetising.

 +  = YUCK

Chilli powder and fruit

The compound capsaicin present in chilli has two effects: it enhances our sense of smell and also heightens our perception of sweetness.

 +  = YUM

Coffee and olives

We evolved to associate bitterness with poison, so combining too many bitter flavours is often unpleasant.

 +  = YUCK

STRANGE BUT TRUE
SPILLING THE BEANS

How many times are refried beans fried?

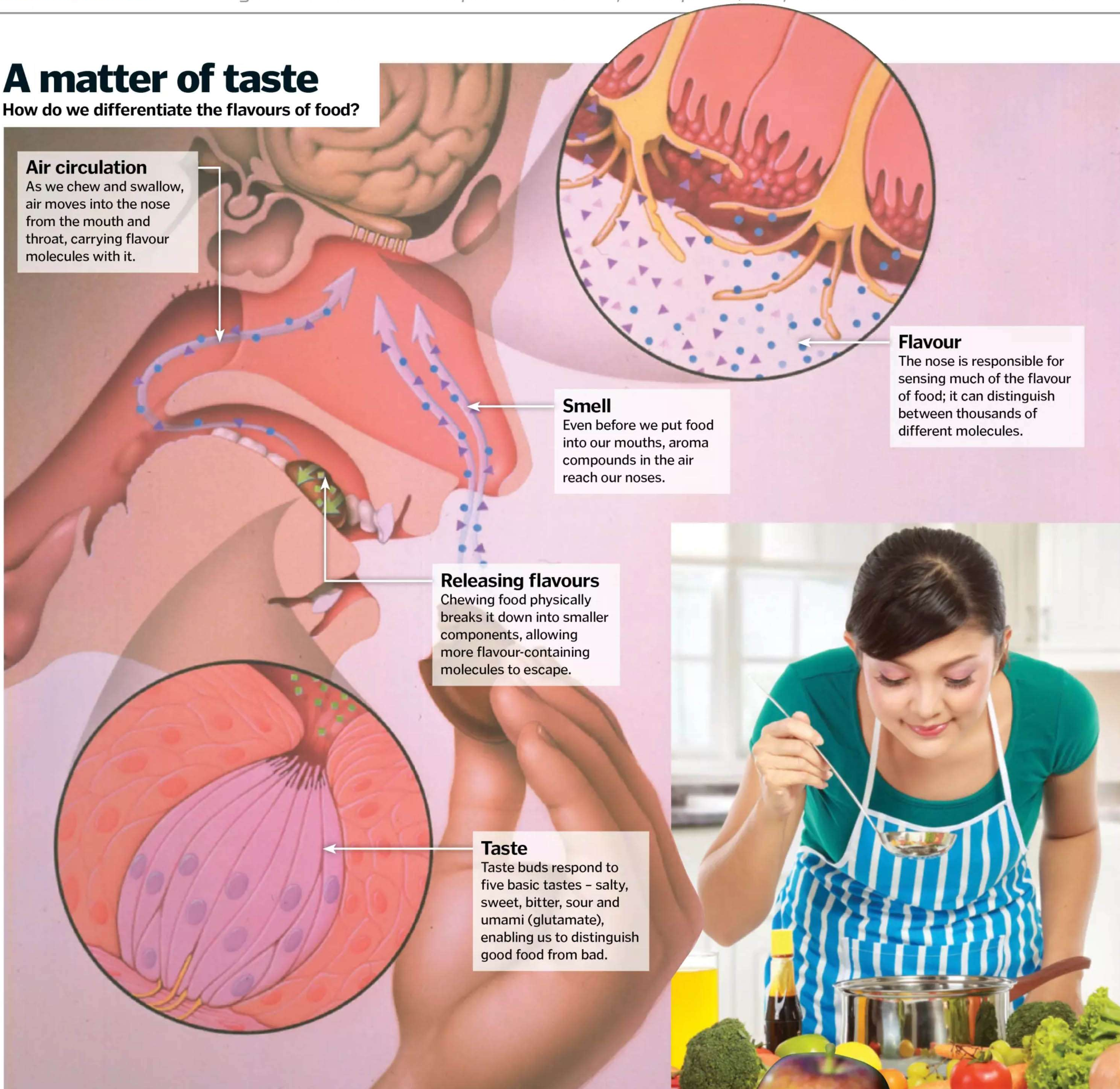
A Once **B** Twice **C** Seven times

Answer:
Refried beans – a traditional Mexican dish of cooked and mashed beans – are actually only fried once. The name 'refried' is the result of a mistranslation. 'Frijoles refritos' actually means 'well-fried beans' but the mistake has stuck.

DID YOU KNOW? *The tongue is not divided into separate areas as often depicted; the five basic tastes are sensed all over*

A matter of taste

How do we differentiate the flavours of food?



Can food make us happy?

People often report cravings for particular foods, and that eating certain meals makes them happy. As a species, we evolved to make eating a pleasant experience, encouraging us to seek out high-calorie food to sustain ourselves when food was scarce.

The human brain has developed reward pathways associated with eating fat and sugar, which release mood-enhancing neurotransmitters, like dopamine and endorphins. Probably the most-studied example is chocolate, which contains phenylethylamine and this affects the body's opioid production.

Comfort food, on the other hand, works more psychologically, and the pleasant feelings that it induces are often linked to sight, smell and taste, which can trigger a sense of nostalgia.